OSTRACODE AND CONODONT DISTRIBUTION ACROSS THE LUDLOW/PŘÍDOLÍ BOUNDARY OF WALES AND THE WELSH BORDERLAND

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ABSTRACT. The ostracodes and conodonts of the Silurian Ludlow/Přídolí Series boundary are documented in detail at Ludlow, and described from across Wales and the Welsh Borderland. The Upper Whitcliffe Formation and its lateral equivalents are characterized by the ostracode *Calcaribeyrichia torosa* and the conodonts *Ozarkodina confluens*, *O. excavata*, *Panderodus serratus* and *Coryssognathus dubius*. The Downton Castle Sandstone Formation and its lateral equivalents are characterized by the ostracodes *Frostiella groenvalliana*, *Londinia arisaigensis*, *L. fissurata* and *Nodibeyrichia verrucosa*. Conodont faunal trends across the Welsh Borderland reflect an increasingly turbulent environment towards the top of the Ludlow Series. The sudden ostracode faunal change at the base of the Downton Castle Sandstone at Ludlow (shelf) contrasts with a gradual change at Long Mountain (basin) and parallels shelf–basin palynofacies. Ostracode faunal variations in the Downton Castle Sandstone Formation at Ludlow coincide with minor lithofacies variations. Local variations in ostracode and land plant spore frequency may be related to proximal channels that delivered sediment off an irregularly prograding shoreline. Ostracodes correlate the base of the Downton Castle Sandstone across the Welsh Borderland to localities in east central Wales where bone beds are absent. Combined conodont and ostracode evidence suggests that the base of the Přídolí Series is at the base of the Downton Castle Sandstone Formation in Britain.

'So brilliantly black are many of the organic fragments, that when discovered, this bed conveyed the impression that it enclosed a triturated heap of black beetles cemented in a rusty ferruginous paste' (Murchison 1839, p. 198). This is the first description of the bed which was first mentioned by Murchison (1834), later described in detail (Murchison 1852) and named the Ludlow Bone Bed (Murchison 1854). Murchison (1839, p. 198) also noted that, 'this bone bed is not merely local, since fragments having the same structure, but of greater thickness than any of Ludford, have been found near Richard's Castle; and there is every reason to believe that it extends through various parts of the Ludlow promontory.' The Ludlow Bone Bed, which consists essentially of acanthodian remains and thelodont dermal denticles, is the lowest of several bone beds in the Ludlow Bone Bed Member at Ludford Corner, Ludlow (Holland *et al.* 1963; Antia 1979*a*, 1980). For the purpose of the present study, other bone beds, either higher in the section at Ludlow or at any other locality in the Welsh Borderland, will be referred to simply as a bone bed, thus implying no correlative significance with the Ludlow Bone Bed itself. Murchison never stated that the Ludlow Bone Bed defined the upper limit of the Silurian System. French workers (Dorlodot 1912; Barrois *et al.* 1918, 1922) mistranslated Murchison (1842, p. 648) and considered the Ludlow Bone Bed as the Siluro-Devonian boundary (White 1950). The Ludlow Bone Bed was then accepted (Stamp 1920, 1923; and subsequent workers) as the base of the Devonian System. The suggestion that the Siluro-Devonian boundary be raised to be coincident with the base of the *Monograptus uniformis* Zone (Holland 1965), led to abandonment of the Welsh Borderland as a standard for the Siluro-Devonian boundary (McLaren 1977). The Siluro-Devonian boundary is now defined at a level coincident with the base of the *M. uniformis* Biozone, within Bed 20 at Klonk in the Czech Republic (Chlupáč 1972; McLaren 1977). This is stratigraphically higher than the Ludlow Bone Bed. To accommodate the strata between these two stratigraphical markers a fourth and youngest series of the Silurian had

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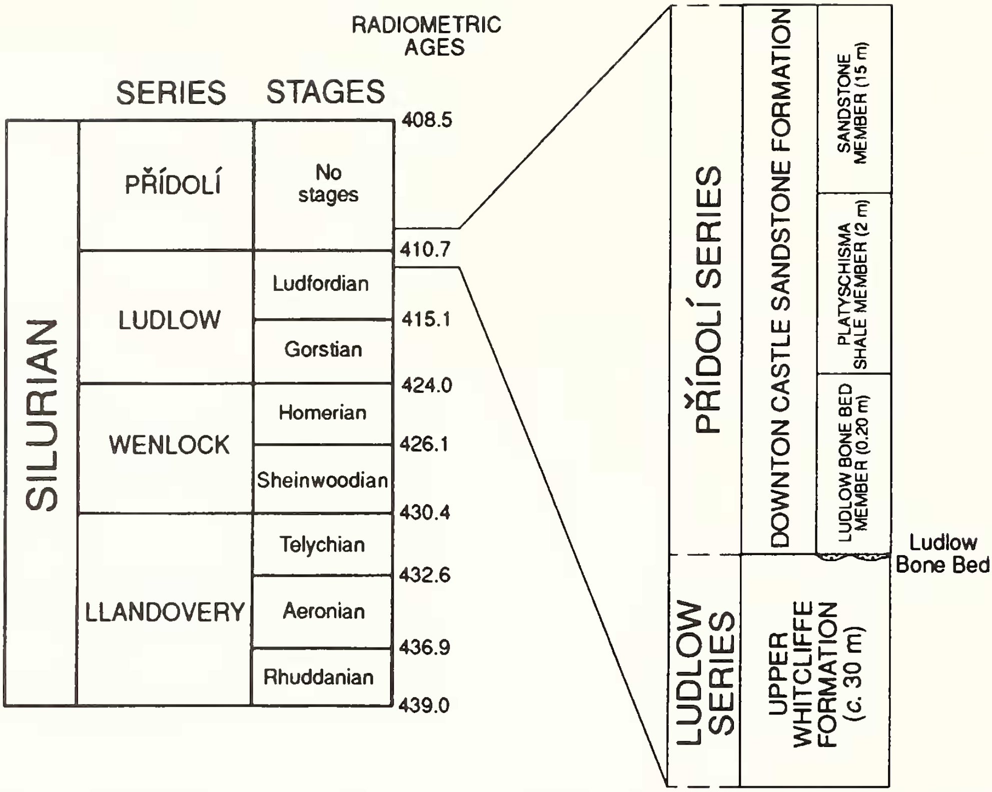
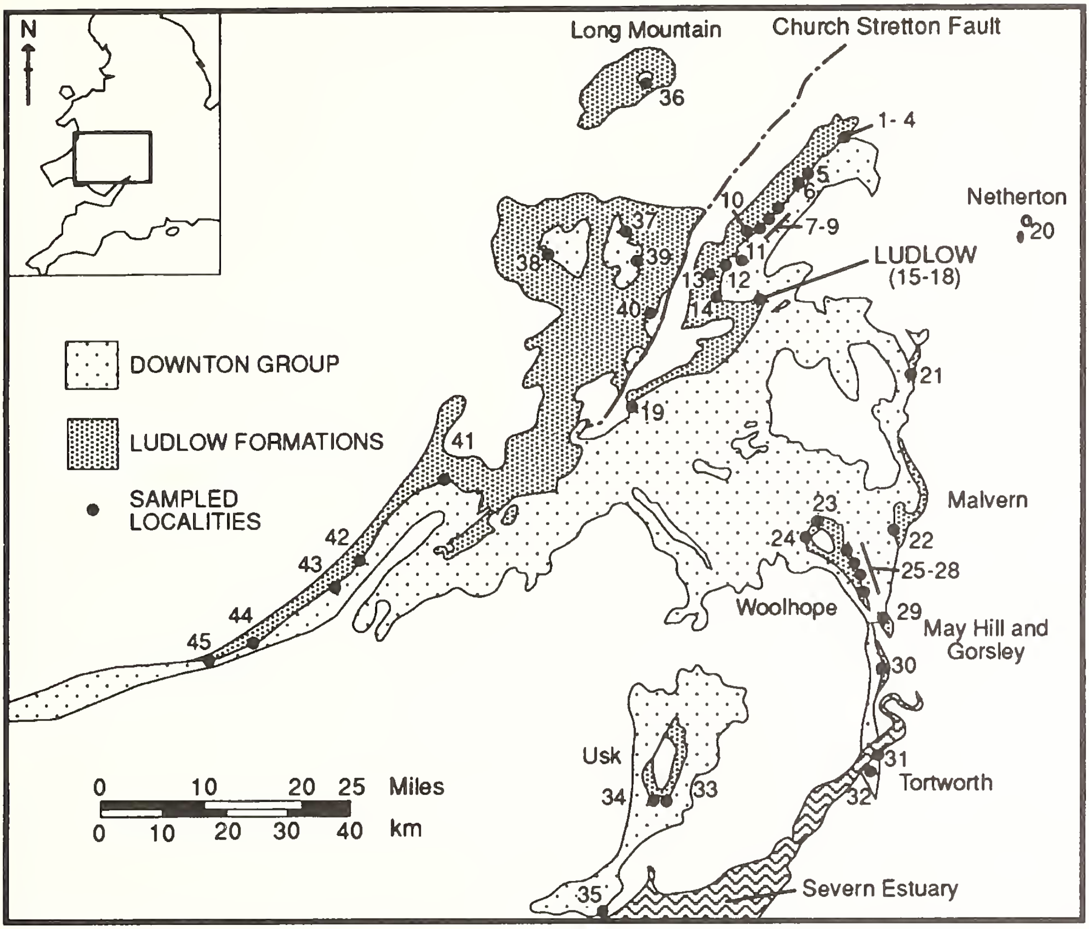


TEXT-FIG. 1. Chronostratigraphy of the Silurian (radiometric dates after Harland *et al.* 1990) and lithostratigraphy of the Upper Whitcliffe and Downton Castle Sandstone formations (after Bassett *et al.* 1982) at the type locality for the Ludlow Bone Bed Member at Ludford Corner, Ludlow, Shropshire (loc. 18).

to be established (Text-fig. 1). The base of the Downton Group at Ludlow (the base of the Ludlow Bone Bed) was a prime contender for the basal stratotype for this series (Bassett *et al.* 1982), as was the base of the Skala Series in Podolia, and the Přídolí Series of the Barrandian area (Prague Basin). There was little support for the Skala section as 'at this level cyclic dolomites dominate the sequence and correlation with the base of the corresponding Downton and Přídolí sequences could be achieved only with the use of limited ostracodal evidence' (Holland 1989, p. 18). Even though the base of the Downton Group could be correlated with graptolitic facies via a complex chain of correlation (Bassett *et al.* 1982), the marine Přídolí succession was eventually confirmed as the fourth series of the Silurian (Bassett 1985). The basal boundary stratotype was designated at Požáry near Prague with the base at a level coincident with the base of the *Monograptus parultimus* Biozone (Kříž *et al.* 1986; Kříž 1989, 1992).

In the Welsh Basin the lithostratigraphical boundary between the Upper Whitcliffe Formation and the Downton Castle Sandstone Formation, corresponds to the base of the Ludlow Bone Bed at Ludford Corner, Ludlow, Shropshire (Text-fig. 1). Ostracodes correlate the base of the Downton Castle Sandstone Formation, via Baltic marine sequences, approximately with the base of the Přídolí Series at the stratotype in the Czech Republic (Siveter 1978, 1989; Bassett *et al.* 1982; Siveter *et al.* 1989; Hansch *et al.* 1991). Conodont evidence has suggested that the base of the Přídolí may be slightly higher than the base of the Downton Castle Sandstone Formation at Ludlow (Schönlaub 1986; Aldridge and Schönlaub 1989). The aims of this paper are:



TEXT-FIG. 2. Outcrop of the Downton Group and Ludlow formations in Wales and the Welsh Borderland (after Bassett *et al.* 1982) showing localities sampled by Miller (1993).

1. To document the detailed distribution of ostracodes and conodonts across the base of the Downton Castle Sandstone Formation at Ludlow and its lateral equivalents, throughout the Welsh Basin.
2. To use conodont and ostracode faunas to test the correlation of the base of the Downton Castle Sandstone Formation across the Welsh Basin.
3. To integrate the results with published palynofacies (Richardson and Rasul 1990) and sedimentological studies at coeval sections.
4. To investigate the correlation of the base of the Přídolí Series, as defined in the Czech Republic, with the base of the Downton Castle Sandstone Formation within the Welsh Basin.

METHODS OF STUDY

Fieldwork. Slightly calcareous lithologies, bone beds and horizons with decalcified macrofauna or ostracode moulds were sampled from localities across Wales and the Welsh Borderland (Text-fig. 2) covering the lateral equivalents of the base of the Downton Castle Sandstone Formation. The local lithostratigraphical units of Cocks *et al.* (1992, figs 3–4) are followed unless stated. Some localities exposing strata immediately above or below this level were also sampled. Detailed sedimentary logs were measured at prolific localities with sampling interval dictated by the presence of calcareous horizons or ostracode moulds. For each sample the minimum practical thickness of strata was collected (0·01–0·1 m) and, where possible, approximately 2 kg of sample. However, sample size was often dictated by unstable overhanging strata or vertical cliff exposures. Additional material has been obtained from a number of sources: British Geological Survey (BGS), Dr R. J. Aldridge (RJA), and Dr David J. Siveter (DJS). Dr Aldridge's samples are suffixed by an asterisk and the original locality numbers retained as they have been used in previous publications (Aldridge 1985; Miller and Aldridge 1993) and the numbers are to be published in a monograph on British Silurian conodonts.

Acid preparation. To recover conodonts and other phosphatic microfossils, slightly calcareous lithologies and bone beds were disaggregated in 10 per cent. acetic acid and, if the acid had little or no effect, crushed in a fly press. All residues were sieved at 75 μm and separated into heavy and light fractions using an aqueous solution of sodium polytungstate (manufactured by Sometu, Berlin) at a specific gravity of 2·80. Each heavy residue was picked completely for conodonts. The dry weight of each sample was taken initially and after treatment, to enable numbers of conodont elements per gram to be calculated.

Ostracode mould fauna preparation. Samples containing ostracode moulds were split in the laboratory, with care taken to keep part and counterpart together. An approximate calculation of ostracode abundance for each bed was obtained by dividing the total number of ostracode valves and carapaces for each bed by the total surface area viewed. Ostracodes with well preserved external moulds were prepared and cast using silicone rubber (manufactured by Ambersil Ltd., Basingstoke) by the method described by Siveter (1982).

LOCALITIES AND HORIZONS

1. Callaughton Mill: roadside exposure, 2·5 km SW of Much Wenlock, Shropshire; SO 6198 9746 (Robertson 1927, p. 86); Whitcliffe Formation, Downton Castle Sandstone Formation with bone bed at base; (BGS 18–151).
2. Willey: quarry behind stables, Willey Estate, Willey, 5 km ESE of Much Wenlock, Shropshire; SO 6731 9912 (White and Coppack 1978, text-fig. 1); Whitcliffe Formation, Downton Castle Sandstone Formation with bone bed at base and 3 m above base; (BGS and CGM).
3. Linley: 6·5 km E of Much Wenlock, Shropshire (White and Coppack 1978, text-fig. 3).

3*a*. Road from Linley Hall to Linley Brook, E of Linley Bridge; SO 6870 9817 (Robertson 1927, loc. L17); Downton Castle Sandstone; (BGS 18–84).

3*b*. Linley Brook, 90 m E of Hem Farm; SO 6920 9820 (Robertson 1927, loc. L18); Downton Castle Sandstone Formation; (CGM and BGS 18–85).

3*c*. Tributary to Linley Brook 1 km E of Linley Bridge; SO 6940 9815 (Robertson 1927, p. 87, loc. L19); Downton Castle Sandstone Formation with bone bed; (BGS 18–85).

4. Dean Brook: tributary to R. Severn 6·5 km E of Much Wenlock, Shropshire (White and Coppack 1978, text-fig. 3).

4*a*. Left bank of Dean Brook at mouth of small dry stream; SO 6955 9915 (Robertson 1927, locs L13 and 14); Downton Castle Sandstone Formation; (BGS 18–92).

4*b*. 40 m N of 4*a*; SO 6875 9955 (Robertson 1927, loc. L16); Downton Castle Sandstone Formation; (BGS 17–123).

5. Brockton: on B4378, 6·5 km SW of Much Wenlock, Shropshire.

5*a*. Stream section opposite Ivy Cottage, Brockton, Corve Dale, Shropshire; SO 5755 9388. Whitcliffe Formation; (BGS 54–267).

5*b*. Road cutting 150 m NE of Brockton cross roads on B4378; SO 579 939; Whitcliffe Formation, Downton Castle Sandstone Formation with bone bed at base; (BGS 19–152).

5*c*. Old quarry behind old school house, Brockton; SO 5765 9400; Whitcliffe Formation; (RJA).

6. Shipton: junction of B4368 and B4378 on Corve Dale, 9 km SW of Much Wenlock, Shropshire.

6*a*. Pathside exposure, 30 m SE of B4368; SO 5634 9186; Whitcliffe Formation; (CGM).

6*b*. Old quarry in farmyard, 150 m at 26° from NE end of St. James Church; SO 5625 9194; Whitcliffe Formation and Downton Castle Sandstone Formation with bone bed at base; (BGS 54–271).

6*c*. Laneside section, 155 m at 125° from SW end of St. James Church; SO 5629 9169; Whitcliffe Formation and Downton Castle Sandstone Formation with bone bed at base; (CGM and BGS 54–271).

7. Aston Munslow: Corve Dale, 10 km NE of Craven Arms, Shropshire.

7*a*. Swan Inn car park; SO 5124 8658; Whitcliffe Formation and Downton Castle Sandstone Formation with bone bed at base; (BGS 54–120, CGM and RJA).

7*b*. Roadside exposure, 120 m NW of 7*a*; SO 5113 8671; Whitcliffe Formation; (CGM and RJA).
8. Diddlebury: roadside exposure on Middlehope road, Diddlebury, Corve Dale, Shropshire; SO 503 858; Whitcliffe Formation; (CGM and RJA).
9. Corfton: roadside cutting, 55 m SE of Sun Inn, Corfton, *c*. 7 km ENE of Craven Arms, Corve Dale, Shropshire; SO 497 846; Downton Castle Sandstone Formation; (CGM and BGS 54–124).
10. Siefton: *c*. 5 km E of Craven Arms, Shropshire.
10*a*. Quarry in Siefton Batch, 1 km NW of B4368, Corve Dale, Shropshire; SO 4770 8475; Whitcliffe Formation; (CGM).
10*b*. Temporary roadside trench; SO 475 833 to 478 835 (Antia 1979*b*); Whitcliffe Formation and Downton Castle Sandstone Formation.
11. Culmington: old quarry S of new house near Culmington, Shropshire; SO 4745 8150; Downton Castle Sandstone Formation with bone bed at base (BGS records); (CGM and BGS 66–101).
12. Onibury: 4 km SSE of Craven Arms, Shropshire.
12*a*. Farmyard exposure, 3 km WNW of Onibury Church; SO 425 796; Upper Whitcliffe Formation; (BGS 54–198).
12*b*. Norton road section, NNE of Onibury; SO 4575 7982 (Shaw 1969); Temeside Bone Bed, Temeside Shales, Downton Group; (DJS).
12*c*. Locality not constrained, on road from Onibury to Norton; Tilestones (Downtown Group); BGS 22–140).
13. Clungunford: 5 km SW of Craven Arms, Shropshire.
13*a*. Lane in wood, 3·2 km E of Clungunford; SO 434 789; Whitcliffe Formation; (BGS 54–196).
13*b*. Old quarry, 150 m E of Brandhill Farm, 2 km E of Clungunford; SO 4236 7883; Whitcliffe Formation; (CGM and BGS 54–197).
14. Downton Estate: area around Downton Castle, *c*. 6 km W of Ludlow, Shropshire.
14*a*. Bank to SE of Downton Bridge, Downton Estate; SO 4449 7427 (Whitaker 1962); Upper Whitcliffe Formation, Ludlow Bone Bed Member with bone bed at base and Platyschisma Shale Member of Downton Castle Sandstone Formation; (DJS).
14*b*. Weir Quarry, NW bank of the River Teme, *c*. 275 m NE of Bringewood Forge Bridge, Downton Estate; SO 4560 7525 (Shaw 1969; Richardson and Rasul 1990, loc. 1); Upper Whitcliffe Formation, Ludlow Bone Bed Member with bone bed at base, Platyschisma Shale Member and Sandstone Member of Downton Castle Sandstone Formation; (CGM).
14*c*. Track section in field to S of Downton Castle Bridge; SO 4442 7402 (Whitaker 1962); Platyschisma Shale Member (including Downton Bone Bed) and Sandstone Member of Downton Castle Sandstone Formation; (collected in 1968 by Dr L. Jeppsson, University of Lund, Sweden).
15. Whitcliffe Quarry: S bank of the River Teme, Ludlow, Shropshire.
15*a*. 250 m W of Ludford Bridge; SO 5098 7414 (Siveter *et al*. 1989, loc. 3.1f); boundary between Lower Whitcliffe Formation and Upper Whitcliffe Formation at top to convoluted bedding; (CGM and RJA).
15*b*. 40 m W of 15*a*; SO 5096 7414; same strata exposed as at 15*a*; (CGM).
15*c*. 60 m W of 15*a*; SO 5092 7415; possible boundary between Lower and Upper Whitcliffe formations marked by similar convoluted bedding to 15*a*; (CGM and RJA).
15*d*. 120 m W of 15*a*; SO 5089 7416; Lower and Upper Whitcliffe formations; (CGM and RJA).
16. Whitcliffe: car park to Charlton Arms Hotel, near Ludford Bridge, Ludlow, Shropshire; SO 5116 7416; Upper Whitcliffe Formation, *c*. 10 m below Ludlow Bone Bed; (RJA).
17. Ludford Lane: N side of Whitcliffe Road (formerly Ludford Lane), Ludlow, Shropshire.
17*a*. Next to roadsign 90 m W of junction with A49; SO 5116 7413 (Siveter *et al*. 1989, loc. 3.2b); Upper Whitcliffe Formation, Ludlow Bone Bed Member with multiple bone beds and Platyschisma Shale Member, Downton Castle Sandstone Formation; (CGM, DJS, RJA and BGS).
17*b*. 80 m W of junction with A49; SO 5117 7413; strata sampled as for 17*a*.
17*c*. 70 m W of junction with A49; SO 5118 7413; strata exposed as for 17*a*, *b*, Upper Whitcliffe Formation only sampled.
18. Ludford Corner: at junction of A49 with Ludford Lane, Ludlow, Shropshire; SO 5124 7413 (Siveter *et al*. 1989, loc. 3.2a); Upper Whitcliffe Formation§, Ludlow Bone Bed Member§ with multiple bone beds, Platyschisma Shale Member and Sandstone Member of Downton Castle Sandstone Formation; only units suffixed by § and the lowermost 0·07 m of the Platyschisma Shale Member sampled.
19. Kington: Hereford and Worcester town *c*. 25 km SW of Ludlow.

19*a*. Section on N side of Kington by-pass; SO 2998 5706 (Holland and Williams 1985, loc. 5); Upper Whitcliffe Formation, multiple bone beds in Ludlow Bone Bed Member, Platyschisma Shale Member, Sandstone Member of Downton Castle Sandstone Formation.
19*b*. Lane-side exposures on Newton Lane; SO 2902 5716 (Holland and Williams 1985, loc. 3); Upper Whitcliffe Formation, multiple bone beds in Ludlow Bone Bed Member and Platyschisma Shale Member of Downton Castle Sandstone Formation.
20. Netherton: old tramway, SW side of reservoir, Salt Wells Nature Reserve, Primrose Hill, Netherton, Birmingham; SO 9358 8732 (King and Lewis 1912; Ball 1951); Whitcliffe Formation, Ludlow Bone Bed Member of Downton Castle Sandstone Formation; (CGM, RJA and DJS).
21. Abberley: village *c*. 15 km NW of Worcester, Hereford and Worcester.
21*a*. Small quarry 50 m S of Abberley Hall; SO 745 663; Whitcliffe Flags Member, Upper Ludlow Formation; (BGS 32–28).
21*b*. Old quarry to E of road 100 m SE of Camp Farm, Great Whitley, near Abberley; SO 7405 6505; Whitcliffe Flags Member, Upper Ludlow Formation; (BGS 28–212).
21*c*. Woodbury (working) Quarry, 1500 m at 33° from church at Shelsey Beauchamp, Worcestershire; SO 743 637 (Mitchell *et al*. 1962; Phipps and Reeve 1967); Whitcliffe Flags Member, Upper Ludlow Formation; (BGS 28–215 and 59–146).
21*d*. Small quarry 100 m SW of Rodge Hill Farm, Shelsey Beauchamp, Worcestershire; SO 746 622; Whitcliffe Flags Member, Upper Ludlow Formation; (BGS 28–207).
22. Brockhill Quarry: 250 m NNE of Brockhill Farm, Colwall, near Malvern Wells, Hereford and Worcester; SO 7568 4394 (Penn and French 1971, loc. 38); Whitcliffe Flags Member, Upper Ludlow Formation, Downton Castle Sandstone Formation with bone bed at base; (CGM, RJA and BGS 28–281).
23. Perton Lane: exposures to the E of Perton Lane, Perton, 5 km NNW of Woolhope, Hereford and Worcester.
23*a*. 20 m S of 3-way road junction at Perton; SO 5971 4035 (Squirrell and Tucker 1960, text-fig. 2, loc. F); Upper Perton and Rushall beds; (CGM, DJS and RJA).
23*b*. 20 m S of 23*a* at base of cliff section; SO 5969 4031 (Squirrell and Tucker 1967, text-fig. 5, loc. 2); Upper Perton Beds; (CGM and RJA).
24. Prior's Frome: exposures opposite Yew Tree Inn, Prior's Frome, Woolhope *c*. 5 km ESE of Hereford, Hereford and Worcester; SO 5662 3901 (Gardiner 1927, text-fig. 4; Squirrell and Tucker 1982; Brandon 1989).
24*a*. Old quarry face; Upper Perton Beds; (CGM and RJA).
24*b*. To S of old overgrown path; Rushall Beds with bone bed at base; (CGM, RJA and BGS 59–235).
25. Caerswell Farm: 3·5 km SW of Woolhope, Hereford and Worcester; SO 6440 3380; Upper Perton Beds and Rushall Beds with bone bed at base; (CGM and BGS 59–147).
26. Whittock's End Farm: 550 m W of Whittock's End Farm, 3 km S of Much Marcle, Hereford and Worcester; SO 6540 2990; Rushall Beds with bone bed at base; (BGS 59–147).
27. Rushall: Roadside exposure at Rushall, 3 km ESE of Woolhope, Hereford and Worcester; SO 6410 3481 (Squirrell and Tucker 1967, loc. 18); Upper Perton Beds, Rushall Beds with bone bed at base; (CGM).
28. Bodenham Farm: small quarry immediately to N of Bodenham Farm, 5·5 km SE of Woolhope, Hereford and Worcester; SO 6524 3201 (Squirrell and Tucker 1967, loc. 19); Lower Perton Beds and Upper Perton Beds with bone bed at base.
29. Gorsley: Linton Quarry, 4 km W of Newent, Gloucestershire; SO 6770 2570 (see Lawson (1954) for local lithostratigraphical names); Wenlock Limestone, unconformity, Upper Blaisdon Beds, unconformity, Upper Longhope Beds with phosphatic pebble bed at base, Cliffords Mesne Sandstone with phosphatic pebble bed at base.
30. Longhope: exposures around Longhope Village, Mayhill, Gloucestershire.
30*a*. Exposure behind Longhope railway station; SO 6910 1901 (Lawson 1955, 1967, 1982); Upper Longhope Beds, Cliffords Mesne Sandstone with phosphatic pebble bed at base.
30*b*. Road cutting on A4136, Longhope Village by-pass; SO 692 186 (Lawson 1982, loc. 19); same strata as for 30*a*; (RJA).
30*c*. Stream section at Wood Green; SO 6930 1670 (Lawson 1955, text-fig. 1, loc. C); Upper Longhope Beds, Cliffords Mesne Sandstone with phosphatic pebble bed at base.
31. Tite's Point: exposures on S bank of Severn Estuary near Berkeley Arms, Purton, Gloucestershire.
31*a*. Ditch to S of tow path of Purton-Gloucester canal, 180 m at 244° from the Berkeley Arms; SO 6897 0438 (Cave and White 1971); Whitcliffe Formation; (BGS 62–254).

31*b*. Foreshore of Severn Estuary, 250 m W of Berkeley Arms, Tite's Point; SO 688 046 (Cave and White 1971, text-fig. 2; Curtis 1982); Upper Leintwardine Formation, Whitcliffe Formation, and Downton Castle Sandstone Formation with bone bed at base; (CGM and RJA).
32. Brookend Borehole: Vine Farm, 3 km N of Berkeley, Gloucestershire; SO 6877 0230 (Cave and White 1968, 1978); Elton/Bringewood Beds, Leintwardine Beds, Whitcliffe Formation, Downton Castle Sandstone Formation and Thornbury Beds.
33. Brook House: exposure on W bank of Cwm-ffrwd Brook near Brook Cottage, *c*. 2 km WSW of Llangybi, Usk Valley, Gwent; SN 356 957 (Walmsley 1959, text-fig. 7, 1982); Upper Llangibby Beds and Speckled Grit Beds with bone bed at base; (CGM).
34. Usk: exposures around the town of Usk, Gwent (Walmsley 1959); Speckled Grit Beds with fragmentary fish remains.
34*a*. A few metres below the wall in Llandegveth church yard, Llandegveth, 6·5 km SW of Usk; SN 338 957.
34*b*. Old quarry 400 m SW of Llangybi Castle; SN 365 972.
34*c*. Dingle immediately N of Granary Farm; SN 322 968.
34*d*. Stream section 500 m N of Llanddewi Court; SN 316 982.
35. Rumney Borehole: E of R. Rhymney, *c*. 1·5 km W of Rumney, Cardiff; ST 2108 7925 (Waters and White 1978); Wenlock Series extending through Ludlow Series including Llanedeyrn Formation, overlain by Raglan Mudstone Formation with fragmentary fish remains at base.
36. Long Mountain: exposures around the Long Mountain, NW Shropshire, *c*. 8 km W of Welshpool, Powys.
36*a*. Wallop Hall: exposure under trees near ruins of Wallop Hall, Lower Wallop, 2·7 km SW of Westbury, Long Mountain, Shropshire; SJ 3150 0725 (Richardson and Rasul 1990, loc. 5); Wallop Hall Member of Causemountain Formation with bone bed.
36*b*. 800 m WSW of March Manor Farm; SN 330 103; Causemountain Formation; (BGS 17–40).
37. Nantyrhynau Quarry: exposure behind barn, 5 km NNW of Felindre, Powys; SO 1602 8588; Cefn Einion and Clun Forest formations; (CGM and BGS 143–1776).
38. Felindre: village of Felindre, Powys; SO 1698 8110, *c*. 13 km W of Clun, Shropshire.
38*a*. Medwaled Brook: dry stream bed, *c*. 3 km NNW of Felindre, Powys; SO 1534 8391 to SO 1568 8389 (Earp 1938, p. 138); discontinuous exposures showing general succession through uppermost Cefn Einion Formation into Clun Forest Formation.
38*b*. Stonehouse Dingle: 1 km SE of Felindre, Powys; SO 1712 7983 to 1757 8016 (Earp 1940, p. 7); same strata as for 38*a*.
38*c*. Hendre Farm: trackside exposure, 1·7 km NW of Felindre, Powys; SO 1538 8220; Cefn Einion Formation; (CGM).
39. Clun: *c*. 20 m NNW of Ludlow, Shropshire (Earp 1940).
39*a*. Within's Wood: cutting for new forestry path near Within's Wood, Clun Forest, Shropshire; SO 317 836; Clun Forest Formation with one well-developed bone bed and a succession of thin bone beds. (CGM).
39*b*. Clun Forest: floor of forestry track, near Lydbury North, Shropshire; SO 3176 8317; similar to Green Downton Formation of Holland (1959); (CGM and BGS).
39*c*. Roadside exposure at Bryn, 1·2 km SE of Cefn Einion, Shropshire; SO 2951 8535; Cefn Einion Formation; (BGS).
39*d*. Hurst Mill: exposure next to forestry track in Radnor Wood, *c*. 1·5 km ENE of Clun, Shropshire; SO 3162 8128; Cefn Einion Formation; (CGM and BGS).
39*e*. Five Turnings Outlier: old quarry, 280 m E of Black Garn Farm; SO 297 759 (Stamp 1918, p. 237); Cefn Einion Formation with an exposure gap followed by lowest Clun Forest Formation.
40. Knighton: town *c*. 23 km W of Ludlow, Shropshire.
40*a*. Old quarry immediately W of bridge on Gwernaffel Estate; SO 273 706 (Holland 1959, p. 462, 1988; Richardson and Rasul 1990, loc. 6); Upper Llan-wen Hill and *Platyschisma helicites* beds.
40*b*. Stream section SSE of Middle Pitts Cottages; SO 3120 7176 (Holland 1959, p. 463); Upper Llan-wen Hill and *Platyschisma helicites* beds; (DJS).
40*c*. Meeting House Lane: discontinuous track and trackside exposures on steep track from Meeting House Farm to Llan-wen Hill; SO 3023 6940 (Holland 1959; Allender *et al*. 1960); Upper Llan-wen Hill Beds, *Platyschisma helicites* Beds (including small bone bed), Green Downton and Yellow Downton formations; (DJS).
41. Builth Wells: NW of Gwenddwr, on bank of Nant Gwenddwr, 5 km SW of Builth Wells, Powys; SO 061 436 (Straw 1930, p. 84; 1937); *Holopella conica* Beds and Green Marls.

42. Cwm Graig Ddu: valley WSW of Builth Wells, 4 km SSE of Garth; SN 968 465 (Straw 1953, p. 217); *Holopella conica* Beds overlain by Long Quarry Formation (formerly Tilestones) with junction marked by line of quarry workings.
43. Capel Horeb: N side of A 40, 5·5 km ESE of Llandovery; SN 8445 3234 (Cwm Dwr section of Potter and Price 1965; Siveter *et al.* 1989, loc. 5.8); Upper Roman Camp Formation (= Lower Whitcliffe Formation) unconformably overlain by Long Quarry Formation and Raglan Marls Group; (CGM, RJA and BGS).
44. Sawdde Gorge: river valley *c.* 10 km SW of Llandovery, Dyfed.
44*a*. Exposure in stream bed NW of main bridge over R. Sawdde at Pont-ar-llechau; SN 7280 2447; Lower Roman Camp Formation (= Upper Leintwardine Formation), Long Quarry Formation.
44*b*. Small quarry behind Three Horseshoes Inn, Pont-ar-llechau; SN 7279 2446, (Bassett 1982, text-fig. 2, loc. 6); Long Quarry Formation.
44*c*. Exposure next to forestry track; SN 7372 2418 (Bassett 1982, text-fig. 2, loc. 7G; Siveter *et al.* 1989, loc. 5.5i); Long Quarry Formation.
45. Cennen Valley: 4 km SSW of Llandeilo, Dyfed.
45*a*. Cutting W of A476; SN 6100 1908 to 6102 1902 (Siveter *et al.* 1989, loc. 5.6e); Cennen Formation (= possible uppermost Ludlow Series) and Long Quarry Formation; (BGS and RJA).
45*b*. Small quarry above A483, S of Llandeilo; SN 6145 1915 (Siveter *et al.* 1989, loc. 5.7); Long Quarry Formation.

REPOSITORIES

Illustrated material with the prefix PM is deposited in the Natural History Museum (London) and with the prefix BGS is deposited at the British Geological Survey (Keyworth). A representative suite of specimens (LEIUG 14555–14566) collected by Miller (1993) is held at the Department of Geology, University of Leicester. Tables of data have been deposited with the British Library, Boston Spa, Yorkshire, UK, as Supplementary Publication No. SUP 14045 (17 pp.).

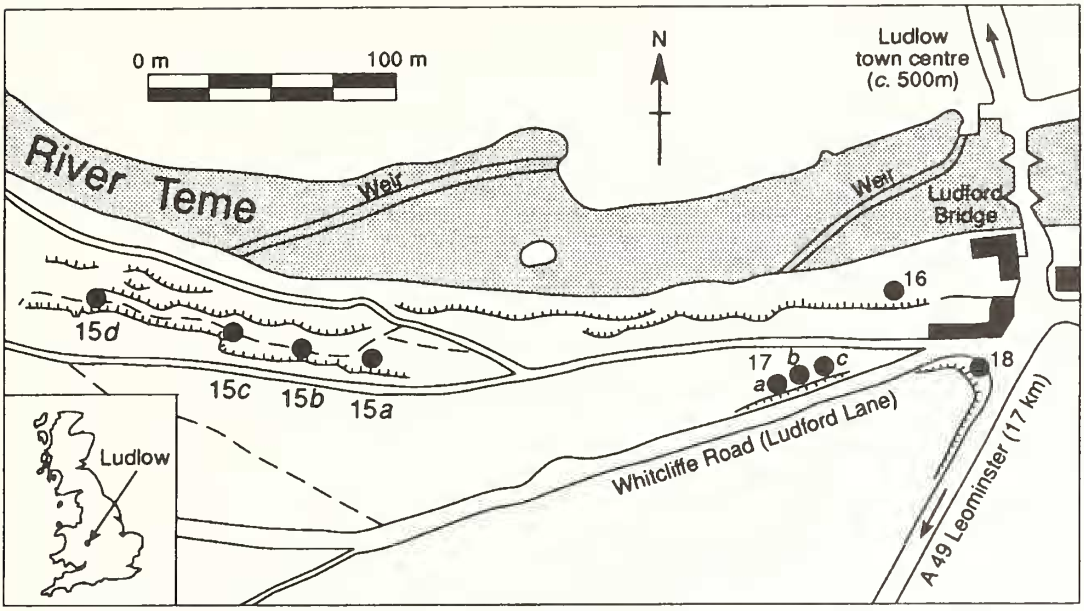
SECTIONS AT LUDLOW, SHROPSHIRE

Upper Whitcliffe Formation

The base of the Upper Whitcliffe Formation is defined (Holland *et al.* 1963, p. 123) at the base of the bed above a convoluted horizon at the disused Whitcliffe Quarry (loc. 15*a*, Text-figs 3–4). Convoluted bedding is well developed at the 'dog-leg' of the exposure at 15*c* and for the purposes of this study has been taken as the topmost bed of the Lower Whitcliffe Formation, although the section is faulted and the convoluted bed is considerably thicker at 15*c* than at 15*a* (Text-fig. 4). As there are no continuous exposures through the Upper Whitcliffe Formation at Ludlow, the sampling interval throughout the formation is irregular and ranges from 0·05 m to approximately 10 m. Localities 15 and 16 are cliff exposures and give an almost complete coverage of the formation (Text-fig. 5). The top of the Upper Whitcliffe Formation is at the base of the Ludlow Bone Bed Member at localities 18 (Text-figs 1, 3, 6), and the formation is approximately 32 m thick at Ludlow (Siveter *et al.* 1989, text-fig. 30).

Conodont distribution. Conodonts were recovered from calcareous to slightly calcareous lithologies which occur sporadically throughout the Upper Whitcliffe Formation. Elements are well preserved and pale amber in colour although some specimens are fragmentary, particularly those from the slightly calcareous lithologies which required crushing to extract the fauna. More than 1800 specimens belonging to nine multielement species were extracted and examined from localities 15 to 18. Conodont-bearing samples contain from twenty to 1056 conodont elements per kg (Text-fig. 7).

Conodont faunas from the topmost Lower Whitcliffe Formation and lowermost 5 m of the Upper Whitcliffe Formation (Text-fig. 7) consist dominantly of *Ozarkodina excavata* and *Coryssognathus dubius* elements with minor numbers of *Panderodus serratus* and *O. confluens*. Other less common species include *O. remscheidensis eosteinhornensis*, *O. remscheidensis* ssp. nov. Aldridge, 1985, *O. snajdri* and *O. wimani* (Pl. 1). At the top of the Upper Whitcliffe Formation these less common species become more frequent and the fauna becomes dominated by *C. dubius* and *O. snajdri* with minor numbers of *remscheidensis* subspecies (notably *O. r. eosteinhornensis*) and *O.* cf. *crispa*; the latter only in strata 0·15–0·3 m below the top of the formation. In the



TEXT-FIG. 3. Locations of sampled exposures on the Whitcliffe at Ludlow, Shropshire (after Holland *et al.* 1963, and Siveter *et al.* 1989).

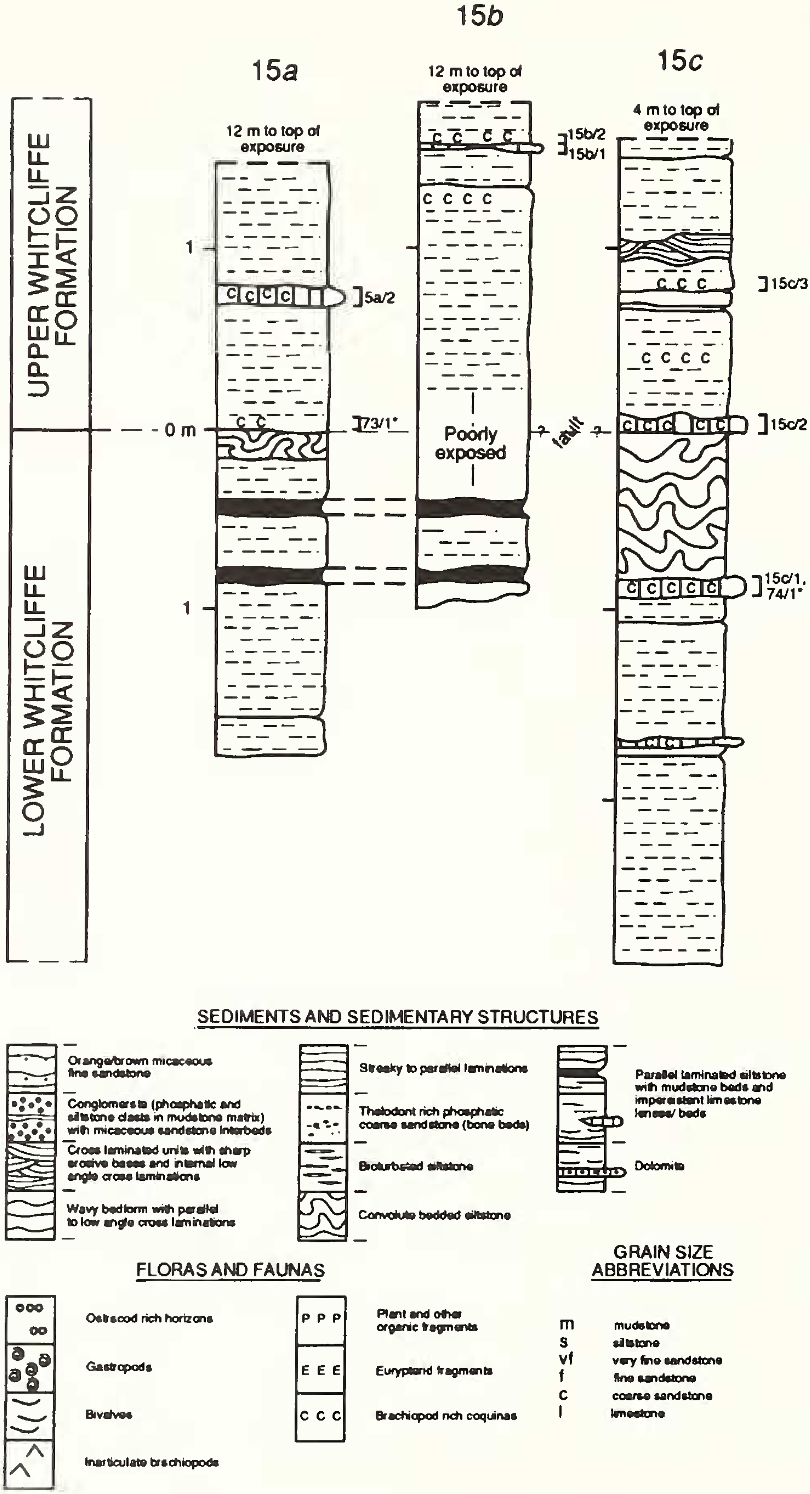
topmost 0·3 m of the Upper Whitcliffe Formation *O. excavata* is much less abundant, *O. confluens* becomes more abundant and *P. serratus* is no longer present. Relative proportions of the individual elements from the apparatus of *O. excavata*, calculated for samples that contain more than fifty elements of *O. excavata*, show insignificant variation in relative percentages of elements (Text-fig. 8).

Ostracode distribution. The Upper Whitcliffe Formation has a virtually monospecific ostracode fauna of *Calcaribeyrichia torosa* (Pl. 2, figs 9–12). This species has been found throughout the Upper Whitcliffe Formation (loc. 17*a* and in samples 15*b*/2, 15*c*/3, 17*c*/1, 18/1) and is mostly confined to decalcified brachiopod coquinas. At localities 17*a–c* and 18, where the uppermost 0·5 m of the Upper Whitcliffe Formation has been sampled 'bed by bed', only a few isolated specimens of *C. torosa* have been recovered (samples 17*c*/1, 18/1, and specimen BGS DEY 3653). *C. torosa* has been reported from both the Lower Whitcliffe and Upper Whitcliffe formations (Siveter 1974). An internal mould of *Hemsiella* cf. *maccoyiana* has been recovered from 0·15 m below the top of the Upper Whitcliffe Formation at Ludford Corner (loc. 18).

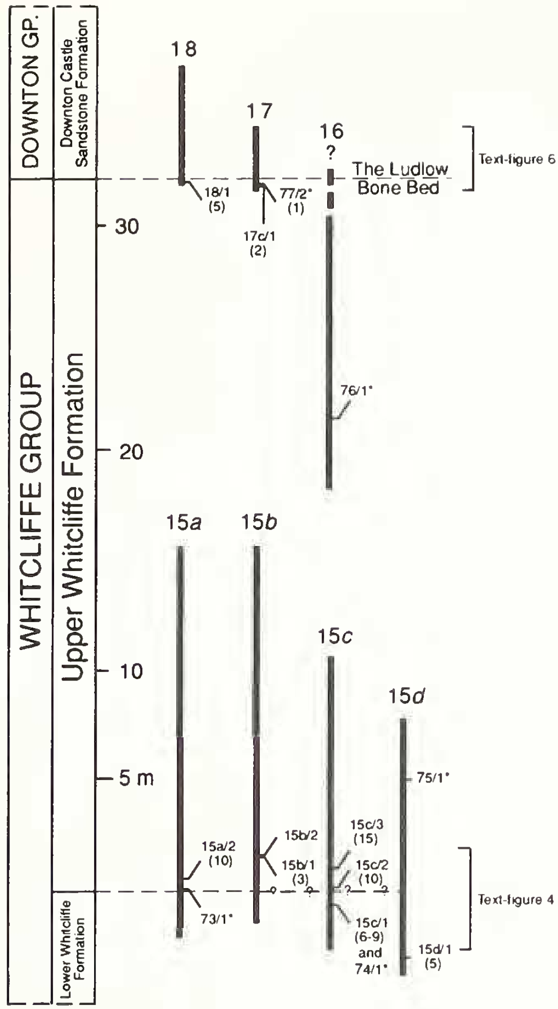
Downtown Castle Sandstone Formation

The base of the Downton Castle Sandstone Formation is defined at locality 18 at the base of the Ludlow Bone Bed (Holland *et al.* 1963). The Downton Castle Sandstone Formation has three members (Text-fig. 1) and has been described in detail by Bassett *et al.* (1982, pp. 6, 14) and Smith and Ainsworth (1989). The upper limit of the Ludlow Bone Bed Member is defined at the top of three closely spaced, millimetre scale, bone beds 0·21 m above its base (Bassett *et al.* 1982, p. 14). These bone beds are discontinuous and the top of the member has not been located accurately at Ludford Lane (locs 17*a–b*). Only a single bone bed has been located at the same level at locality 18 (Text-fig. 6). The Sandstone Member was not sampled for the present study.

Conodont distribution. Conodonts are very rare in the Downton Castle Sandstone Formation, samples containing six to 105 conodont elements per kg, but generally fewer than twenty per kg (Text-fig. 7). Conodont elements have been obtained from bone beds within the Ludlow Bone Bed Member, but elements are extremely fragmentary and abraded making identification difficult (Pl. 1, fig. 11). Only fragments of Pa elements of *O. confluens* and Sa/Sb elements of *C. dubius* have been identified with any certainty (Miller and Aldridge 1993;



TEXT-FIG. 4. Measured logs across the boundary between the Lower and Upper Whitcliffe Formations at Whitcliffe Quarry, Ludlow (locs 15*a*–*c*) showing sampled horizons. Log at Locality 15*a* after Holland *et al.* (1963, text-fig. 6). The key represents all measured logs for the present study.

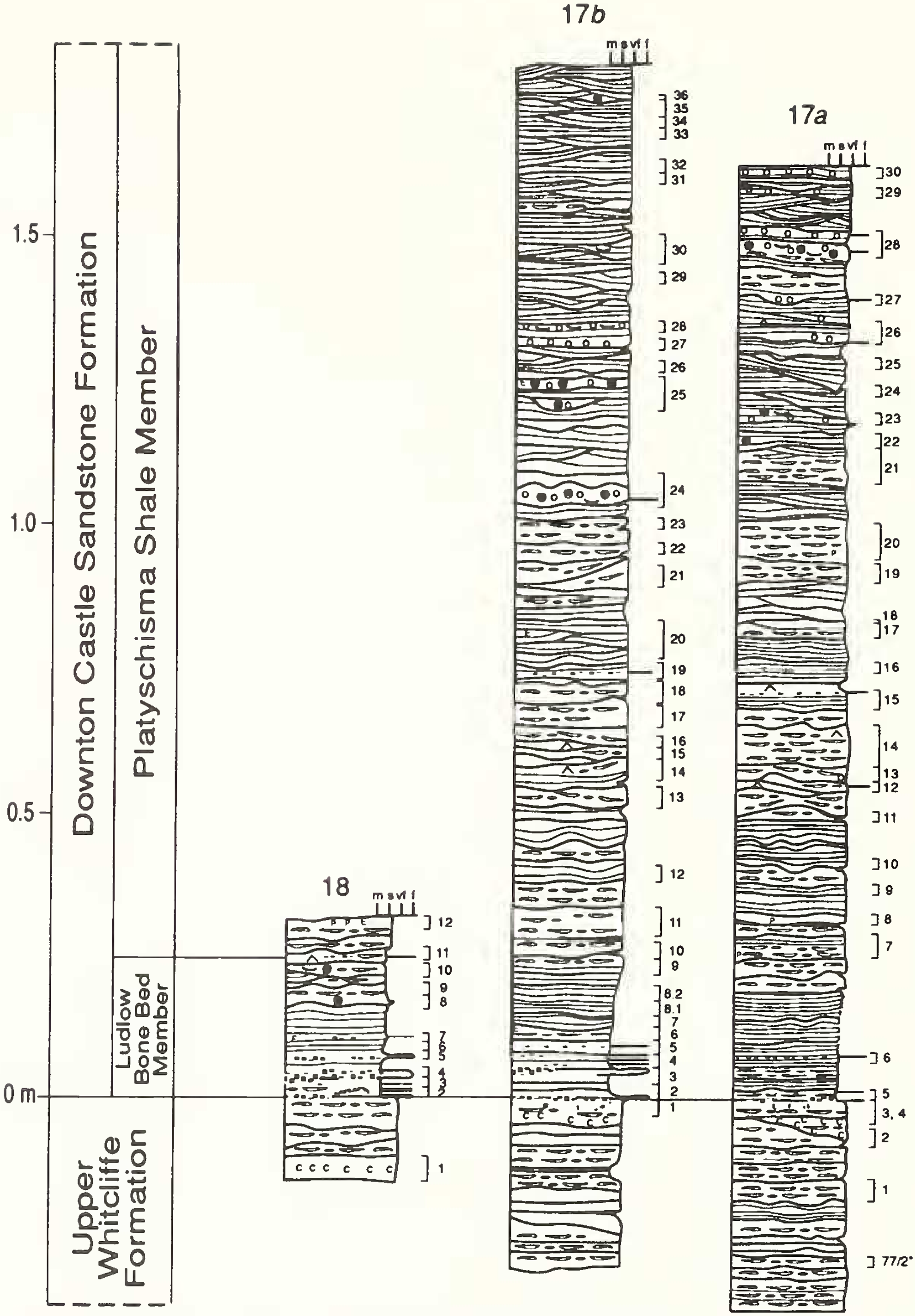


TEXT-FIG. 5. Approximate stratigraphical position of sections (thick black lines) and horizons sampled for conodonts and ostracodes through the Lower and Upper Whitcliffe formations on on the Whitcliffe at Ludlow, Shropshire. Total thickness 32 m (Siveter *et al.* 1989, text-fig. 30). Bed thicknesses given in brackets if known. For detailed sedimentary logs see Text-figures 4 and 6.

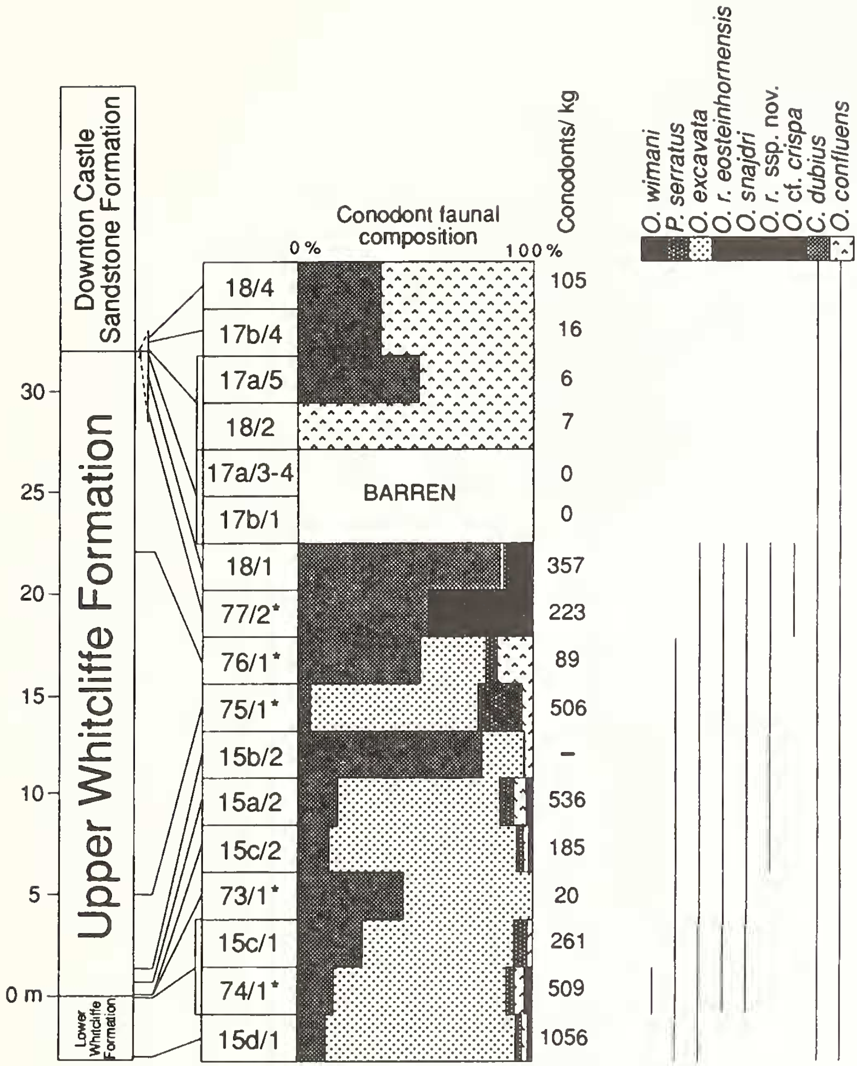
this study). Harley (1861) figured a similar fauna; Aldridge and Smith (1985) also reported fragments of *O. excavata* and Walliser (1966) recorded *O. r. eosteinhornensis* from the Ludlow Bone Bed Member.

Ostracode distribution. A total of 2145 individual ostracode valves and twenty-three specimens of carapaces with co-joined valves has been recovered from the Downton Castle Sandstone Formation at localities 17 and 18 (Text-fig. 9). Individual (mould) specimens are often incomplete and therefore identifiable only to generic level. Relative generic proportions for each bed containing more than ten identifiable ostracodes have been plotted (Text-fig. 9), with ostracode frequency and percentage of carapaces against valves plotted for every bed in the section (Text-fig. 10).

The ostracode fauna shows a similar trend in the two parallel sections 10 m apart (locs 17*a*–17*b*) and also at locality 18. The lowest bed in the Ludlow Bone Bed Member at all three sections contains *Frostiella groenvalliana*, *Londinia arisaigensis*, *L. fissurata*, and *Nodibeyrichia verrucosa* (Pl. 2) in similar relative proportions (Text-fig. 9). In the present study *C. torosa* has not been found above the Upper Whitcliffe Formation, but Bassett *et al.* (1982, text-fig. 6) recorded *C. torosa* within the Ludlow Bone Bed Member at locality 17*a*. This specimen (BGS MR DEY 3694) has been examined by the author and confirms the occurrence of *C. torosa* (with coeval *F. groenvalliana*) at a level 0·08 m above the base of the Ludlow Bone Bed Member.



TEXT-FIG. 6. Measured logs across the boundary between the Upper Whitcliffe and Downton Castle Sandstone Formations at Ludford Corner and Ludford Lane (locs 17–18), showing sampled horizons.

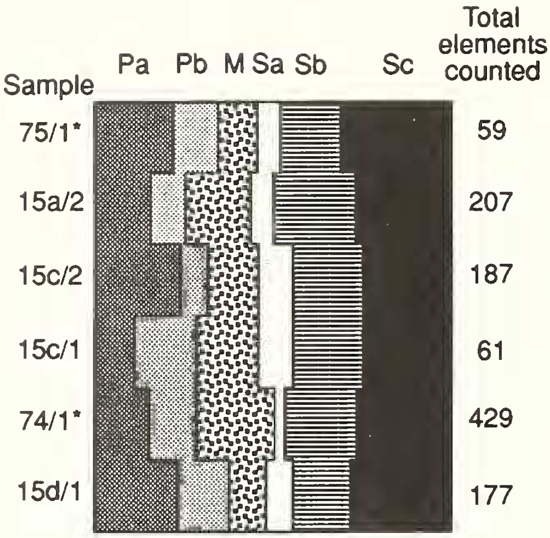


TEXT-FIG. 7. Conodont ranges and compositions of conodont faunas from the Lower Whitcliffe, Upper Whitcliffe and Downton Castle Sandstone Formations at Ludlow, Shropshire (locs 15–18). Positions marked on the lithostratigraphical column are given to the centre of the bed sampled. Bed thicknesses are given in Text-figures 4–6.

The coarsening upwards of the sediments in the Ludlow Bone Bed Member and lowermost 0·15 m of the Platyschisma Shale Member corresponds with an increase in the proportion of *Frostiella* and a parallel decrease in the proportion of *Londinia*. Frequency is relatively high and carapaces are most commonly preserved in these strata reaching a maximum of 15 per cent. with respect to the number of valves in sample 17b/10.

The last occurrence of *N. verrucosa* and the occurrence of bioturbated, synaeresis-cracked siltstones 0·34 m above the base of the Platyschisma Shale Member corresponds to a horizon above which ostracode frequency becomes very low ($< 0{\cdot}1$ ostracode $m^2 \times 10^4$) but carapaces are still preserved.

The onset of cross laminated units with sharp erosive bases corresponds to high frequency ostracode faunas (maximum of 2·0 ostracodes $m^2 \times 10^4$) dominated by *Frostiella* and non-palaeocopes, with *Londinia* very rare



TEXT-FIG. 8. Relative proportions of *O. excavata* elements from the Whitcliffe Group at Whitcliffe Quarry (loc. 15). Samples are arranged in stratigraphical order with the oldest at the base. Sample positions are given in Text-figures 4–5.

EXPLANATION OF PLATE 1

Figs 1, 4. *Ozarkodina remscheidensis eosteinhornensis* (Walliser, 1964). PM X 1164; loc. 8, sample 8/1, Diddlebury, Shropshire; Whitcliffe Formation; Pa element; 1, lateral, and 4, oral views; ×30.

Figs 2, 5. *Ozarkodina remscheidensis remscheidensis* (Ziegler, 1960). PM X 1277; loc. 31*b*, sample 31*b*/3, Tite's Point, Gloucestershire; Whitcliffe Formation; Pa element; 2, lateral, and 5, oral views; ×45.

Figs 3, 6. *Ozarkodina remscheidensis* ssp. nov. Aldridge, 1985. PM X 1156; loc. 7*a*, sample 78/1*, Aston Munslow, Shropshire; Whitcliffe Formation; Pa element; 3, lateral, and 6, oral views; ×45.

Figs 7, 10. *Ozarkodina wimani* (Jeppsson, 1974). PM X 1184; loc. 15*c*, sample 74/1*, Whitcliffe Quarry, Ludlow, Shropshire; Upper Whitcliffe Formation; Pa element; 7, lateral, and 10, oral views; ×85.

Fig. 8. *Ozarkodina excavata* (Branson and Mehl, 1933). PM X 1193; loc. 20, sample 20/1*a*, Netherton, West Midlands; Upper Whitcliffe Formation; Pa element; lateral view; ×50.

Figs 9, 12. *Coryssognathus dubius* (Rhodes, 1953). PM X 1162; loc. 7*a*, sample 39/1*, Aston Munslow, Shropshire; Whitcliffe Formation; Pa element; 9, lateral, and 12, oral views; ×34.

Fig. 11. *Ozarkodina confluens* (Branson and Mehl, 1933). PM X 1188; loc. 17*a*, sample 17*a*/5, Ludford Lane, Ludlow, Shropshire; Ludlow Bone Bed Member, Downton Castle Sandstone Formation; fragment of Pa element; lateral view; ×22.

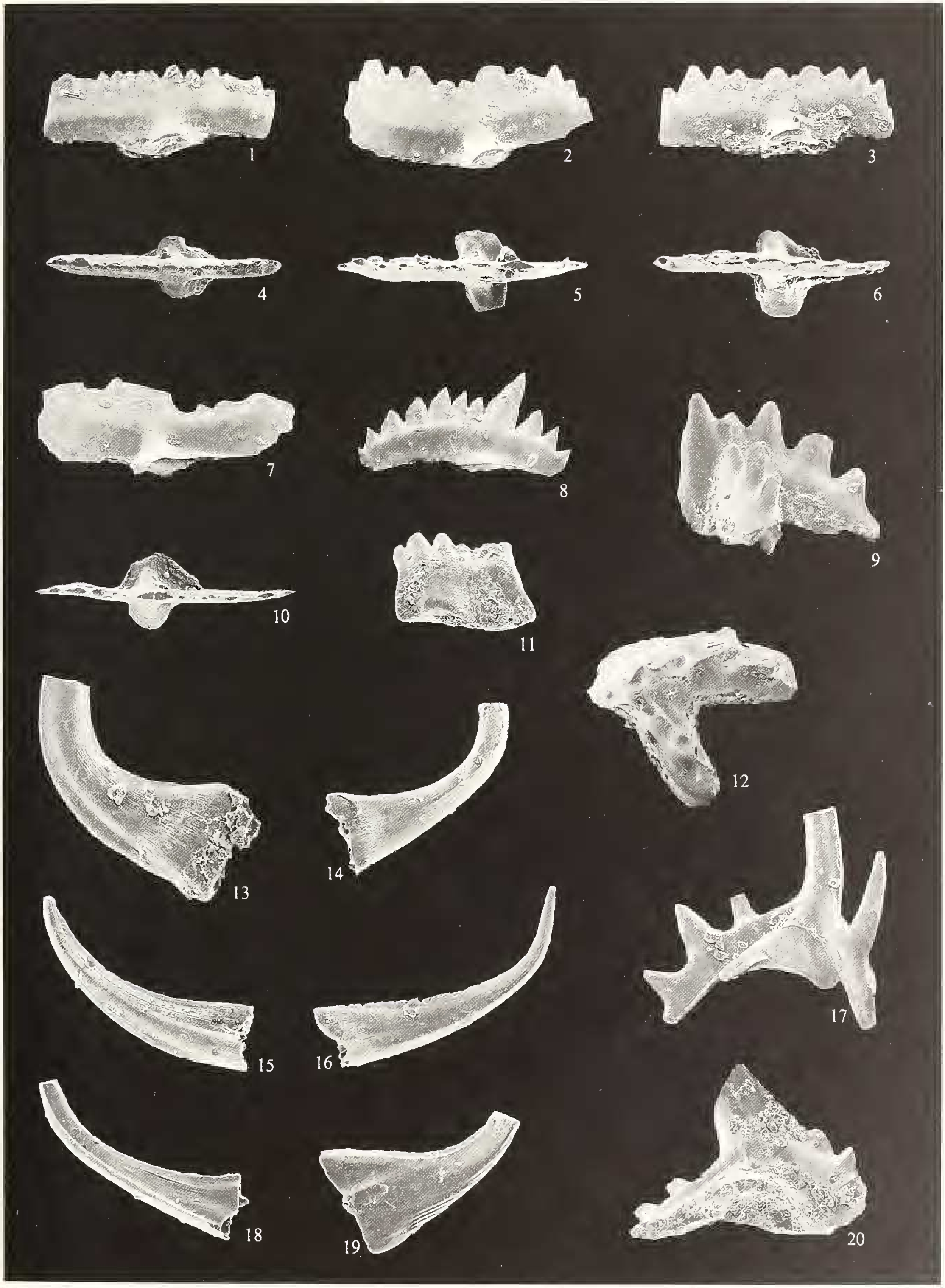
Figs 13–14. *Panderodus recurvatus* (Rhodes, 1953). 13, PM X 1170; loc. 10, sample 10/1, Siefton, Shropshire; Whitcliffe Formation; falciform element; unfurrowed lateral face; ×110. 14, PM X 1214; loc. 20, sample 20/1*a*, Netherton, West Midlands; Upper Whitcliffe Formation; similiform element; unfurrowed lateral face; ×85.

Figs 15–16. *Panderodus serratus* (Rexroad, 1967). 15, PM X 1199; loc. 20, sample 20/1*b*, Netherton, West Midlands; Upper Whitcliffe Formation; falciform element; furrowed lateral face; ×50. 16, PM X 1178; loc. 15*a*, sample 15*a*/2, Whitcliffe Quarry, Ludlow, Shropshire; Upper Whitcliffe Formation; arcuatiform element; unfurrowed lateral face; ×80.

Figs 17, 20. *Oulodus* sp. 17, PM X 1266; loc. 24*a*, sample 162/2*, Prior's Frome, Hereford and Worcester; Upper Perton Beds; Sb element; lateral; ×45. 20, PM X 1280; loc. 31*b*, sample 31*b*/3, foreshore of Severn Estuary, Tite's Point, Gloucestershire; Whitcliffe Formation; Pb element; lateral; ×30.

Fig. 18. *Walliserodus* cf. *sancticlairi*. PM X 1223; loc. 20, sample 20/1*b*, Netherton, West Midlands; Upper Whitcliffe Formation; symmetrical element; lateral; ×100.

Fig. 19. *Dapsilodus obliquicostatus* (Branson and Mehl, 1933). PM X 1172; loc. 10, sample 10/1, Siefton, Shropshire; Whitcliffe Formation; symmetrical element; lateral; ×100.



MILLER, Silurian conodonts

(0–7 per cent.). Ostracodes are concentrated as lags at the bases of beds (Text-fig. 6). Carapaces are no longer preserved.

THE LUDLOW ANTICLINE AND SURROUNDING AREA

The Much Wenlock area

Localities in this area have not yielded abundant conodont or ostracode faunas in this study. White and Coppack (1978) recorded the ostracode *F. groenvalliana* at the base of the Downton Castle Sandstone Formation, from a horizon marked at Willey (loc. 2) by a bone bed. Their collections (BGS) have been

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EXPLANATION OF PLATE 2

All specimens are SEM illustrations of silicone rubber casts of external moulds in lateral view, unless stated.

Figs 1–2. *Hemsiella* cf. *maccoyiana*. 1, PM OS 14146; loc. 38*c*, Felindre, Powys; Cefn Einion Formation; tecnomorphic right valve; ×19. 2, PM OS 14093; loc. 14*b*, sample 14*b*/1, Weir Quarry, Downton, Shropshire; Upper Whitcliffe Formation; heteromorphic left valve; ×22.

Figs 3–4. *Lophoctenella* cf. *scanensis*. 3, BGS RT 336; loc. 4*b*, Dean Brook, Much Wenlock, Shropshire; Whitcliffe Formation; tecnomorphic left valve; ×18. 4, PM OS 14136; loc. 36*a*, sample 36*a*/k, Wallop Hall, Long Mountain, Powys; Causemountain Formation; heteromorphic right valve; ×18.

Figs 5–8. *Nodibeyrichia verrucosa* Shaw, 1969. 5, PM OS 14123; loc. 18, sample 18/2, Ludford Corner, Ludlow Corner, Ludlow, Shropshire; Ludlow Bone Bed Member, Downton Castle Sandstone Formation; tecnomorphic right valve; ×17. 6, BGS SH 3685; loc. 3*b*, Linley Brook, Much Wenlock, Shropshire; Downton Castle Sandstone Formation; heteromorphic left valve; ×14. 7, PM OS 14119; loc. 17*b*, sample 17*b*/3*a*, Ludford Lane, Ludlow, Shropshire; Ludlow Bone Bed Member, Downton Castle Sandstone Formation; tecnomorphic left valve; ×35. 8, PM OS 14138; loc. 36*a*, sample 36*a*/M2, Wallop Hall, Long Mountain, Powys; Causemountain Formation; heteromorphic left valve; ×23.

Figs 9–12. *Calcaribeyrichia torosa* (Jones, 1855). 9, PM OS 14150; loc. 39*d*, Radnor Wood, Clun, Shropshire; Cefn Einion Formation; tecnomorphic right valve; ×27. 10, PM OS 14094; loc. 15*b*, sample 15*c*/3*a*, Whitcliffe Quarry, Ludlow, Shropshire; Upper Whitcliffe Formation; heteromorphic left valve; ×11. 11, BGS DEY 3653; loc. 17*a*, Ludford Lane, Ludlow, Shropshire; Upper Whitcliffe Formation; tecnomorphic left valve; ×12. 12, PM OS 6584; loc. 39*e*, Five Turnings outlier, Clun, Shropshire; Cefn Einion Formation; heteromorphic left valve; ×11.

Figs 13–14. *Londinia arisaigensis* Copeland, 1964. Loc. 18, from loose material dumped after the excavation of Ludford Corner, Ludlow, Shropshire in 1988; Downton Castle Sandstone Formation. 13, PM OS 14125; tecnomorphic right valve; ×13. 14, PM OS 14128; heteromorphic left valve; ×12.

Figs 15–16. *Londinia fissurata* Shaw, 1969. 15, PM OS 14098; loc. 17*a*, sample 17*a*/5*s*, Ludford Lane, Ludlow, Shropshire; Ludlow Bone Bed Member, Downton Castle Sandstone Formation; internal mould of an open tecnomorphic carapace; ×15. 16, PM OS 14112; loc. 17*a*, sample 17*a*/12*d*, Ludford Lane, Ludlow, Shropshire; Platyschisma Shale Member, Downton Castle Sandstone Formation; heteromorphic right valve; ×15.

Fig. 17. Non-palaeocope ostracode. PM OS 14120; loc. 17*b*, sample 17*b*/12*a*, Ludford Lane, Ludlow, Shropshire; Platyschisma Shale Member, Downton Castle Sandstone Formation; ×27.

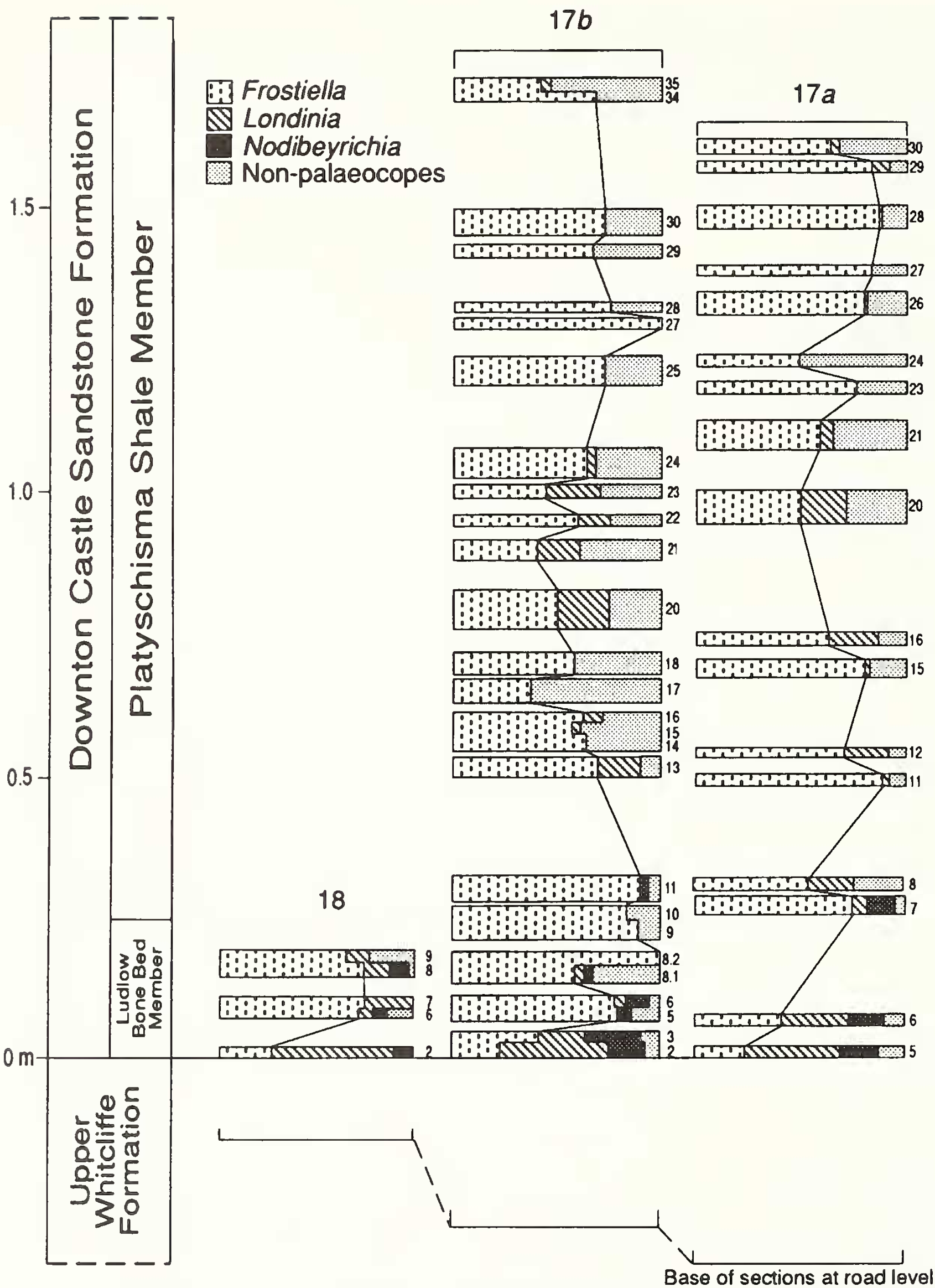
Fig. 18. *Leperditia* sp. PM OS 14641; loc. 17, from loose material from landslide on Ludford Lane, Ludlow, Shropshire in 1993; Platyschisma Shale Member, Downton Castle Sandstone Formation; ×4·3.

Figs 19–20. *Londinia kiesowi* (Krause, 1891). 19, PM OS 14135; loc. 36*a*, sample 36*a*/L, Wallop Hall, Long Mountain; Causemountain Formation; tecnomorphic right valve; ×15. 20, BGS SH 3685; loc. 3*b*, Linley Brook, Much Wenlock, Shropshire; Downton Castle Sandstone Formation; heteromorphic left valve; ×15.

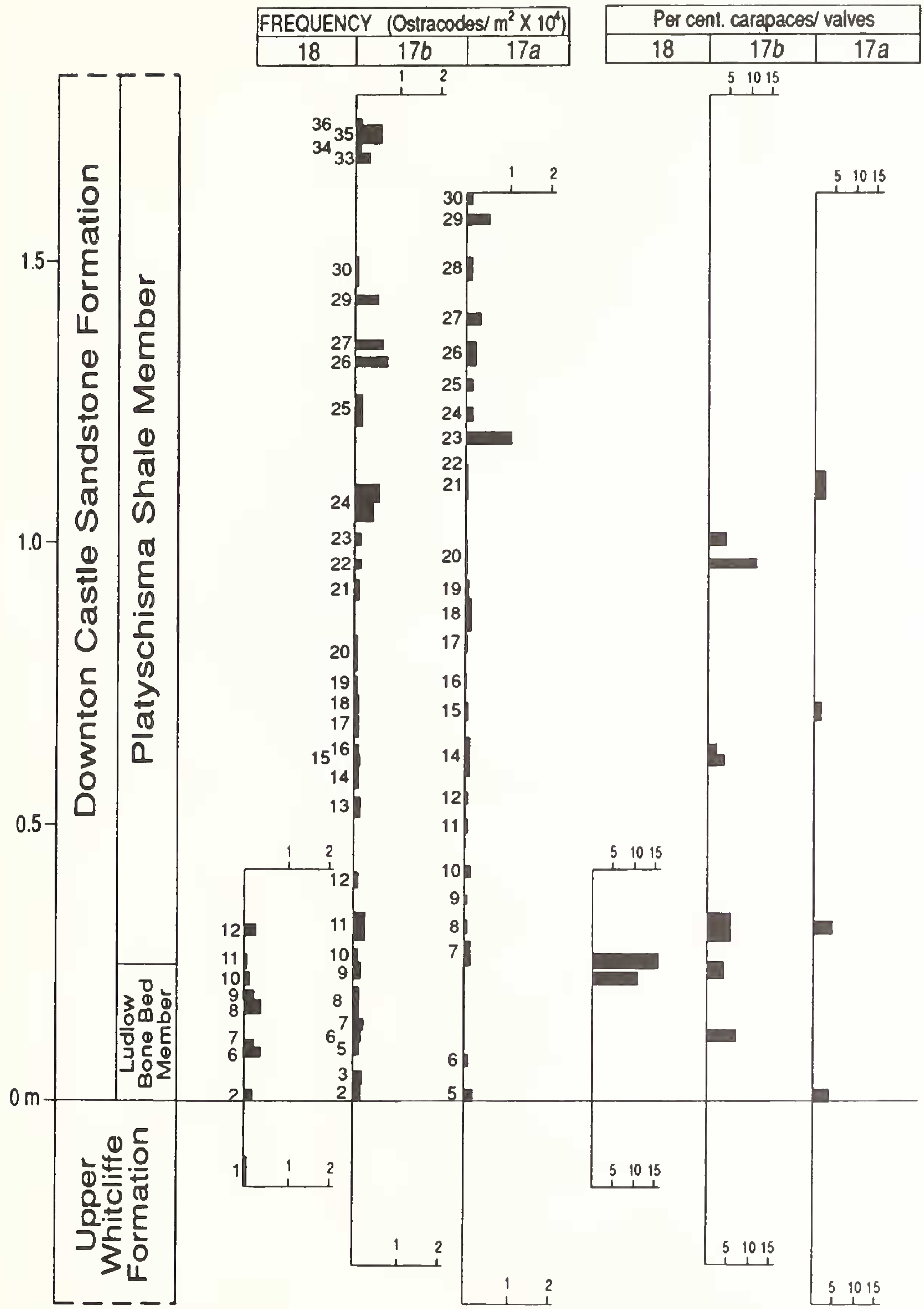
Figs 21–24. *Frostiella groenvalliana* Martinsson, 1963. 21, PM OS 14113; loc. 17*a*, sample 17*a*/26*a*, Ludford Lane, Ludlow, Shropshire; Platyschisma Shale Member, Downton Castle Sandstone Formation; tecnomorphic left valve; ×13. 22, PM OS 14124; loc. 18, Ludford Corner, Ludlow, Shropshire; Platyschisma Shale Member, Downton Castle Sandstone Formation; heteromorphic left valve; ×13. 23, PM OS 14111; loc. 17*a*, sample 17*a*/14*a*, Ludford Lane, Ludlow, Shropshire; Platyschisma Shale Member, Downton Castle Sandstone Formation; tecnomorphic carapace with open valves; ×9. 24, PM OS 13922; loc. 18, from loose material dumped after the excavation of Ludford Corner, Ludlow, Shropshire in 1988; Downton Castle Sandstone Formation; tecnomorphic left valve; ×17.

PLATE 2

MILLER, Silurian ostracodes



TEXT-FIG. 9. Ostracode faunal composition from the Downton Castle Sandstone Formation at Ludford Lane and Ludford Corner (locs 17*a*–*b* and 18). The height of each bar corresponds to the relative thickness of beds from which more than ten identifiable ostracodes were collected. The positions of numbered samples are given in Text-figure 6.



TEXT-FIG. 10. Ostracode frequency and percentage of carapaces with respect to valves for all ostracode samples from the Upper Whitcliffe and Downton Castle Sandstone Formations (locs 17*a*–*b* and 18).

examined by the author and identifications confirmed. Two abraded Pa element fragments of *O. confluens* have been recovered from this horizon. *F. groenvalliana* and *L. fissurata* are recorded from the Downton Castle Sandstone Formation at Callaughton (loc. 1) and Dean Brook (loc. 4*b*) (Robertson, 1927; White and Coppack 1978, p. 28). White and Coppack (1978, p. 29) reported similar ostracode faunas from Linley (locs 3*a–b*), remarking that they closely resemble faunas from the old quarry at Willey (loc. 2). The Downton Castle Sandstone Formation at Linley Brook (loc. 3*b*), has been sampled by the author and contains abundant *F. groenvalliana* associated with the gastropod *Turbocheilus helicites* (J. de C. Sowerby). In one individual calcareous bed at Linley Brook these taxa retain their original calcareous carapaces. The bed has also yielded whole, unabraded conodont specimens of *O. confluens* and *Oulodus* sp. Specimens of similar limestone beds from the Downton Castle Sandstone Formation at Dean Brook (loc. 4) are held at the BGS (Keyworth). Ostracode faunas from the Upper Whitcliffe Formation in the Much Wenlock area are dominated by *C. torosa*, with minor occurrences of *H.* cf. *maccoyiana* and *Lophoctenella* cf. *scanensis* (Pl. 2, fig. 3). The ostracode fauna of the Downton Castle Sandstone Formation is dominated by *F. groenvalliana* with minor occurrences of *L. fissurata*, *L. arisaigensis* and a single specimen of *Londinia kiesowi* (Pl. 2, fig. 20).

Corve Dale

At Brockton (loc. 5*b*), Shipton (locs 6*a–c*), and Culmington (loc. 11) bone beds have been reported at the base of the Downton Castle Sandstone Formation (BGS records; Turner 1973; Antia 1979*a*), but are no longer exposed. Ostracode faunas from the Whitcliffe Formation at Brockton (locs 5*a–b*) and Shipton (loc. 6*a*) contain only *C. torosa*, while those from the Downton Castle Sandstone Formation are almost exclusively dominated by *F. groenvalliana* with minor proportions of *L. arisaigensis*, *L. fissurata* and non-palaeocope ostracodes. *F. groenvalliana*, although confined to the Downton Castle Sandstone Formation, is not present immediately at the base of the Downton Castle Sandstone Formation at any locality on Corve Dale.

Aston Munslow. Two well preserved specimens of *C. torosa* have been recovered from a bed 0–0·02 m below the top of the Whitcliffe Formation at locality 7*a*. A single conodont sample from locality 7*b* (3 m below the top of the formation) is dominated by the conodont *O. excavata* with *O. confluens*, *C. dubius* and minor *P. serratus*. The two faunas from locality 7*a* are very similar to each other, dominated by *C. dubius* with minor *O. confluens*, *O. snajdri* and elements from the *remscheidensis* plexus. The topmost bed of the Whitcliffe Formation has yielded *O.* cf. *crispa* (Pl. 3, fig. 8). 1·63 m of the Downton Castle Sandstone Formation is exposed at locality 7*a*, yielding two poorly preserved specimens of *F.* cf. *groenvalliana* and *L.* cf. *arisaigensis*. *O. confluens* (Pa and Pb elements) and *C. dubius* are present in a laterally discontinuous bone bed up to 0·05 m thick at the base of the Downton Castle Sandstone Formation which has produced 122 conodont elements per kg.

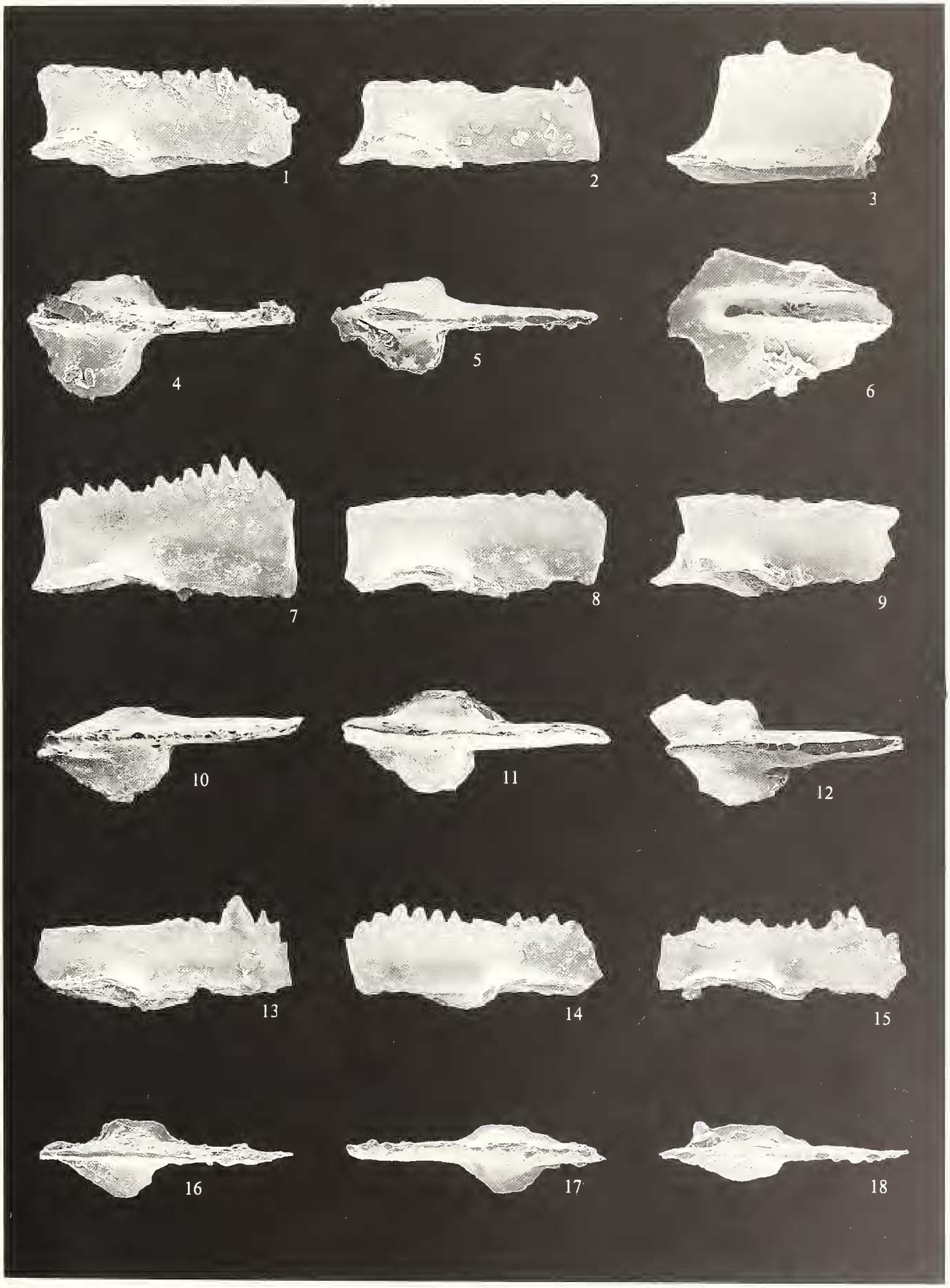
EXPLANATION OF PLATE 3

Figs 1–2, 4–5. *Ozarkodina crispa* (Walliser, 1964). 1, 4, PM X 1276; loc. 31*b* sample 31*b*/7, foreshore of Severn Estuary, Tite's Point, Gloucestershire; Whitcliffe Formation; Pa element; 1, lateral, and 4, oral views; ×60. 2, 5, PM X 1263; loc. 24*a*, sample 162/2*, Prior's Frome, Hereford and Worcester, Upper Perton Beds; Pa element; 2, lateral, and 5, oral views; ×45.

Figs 3, 6–12. *Ozarkodina* cf. *crispa*. 3, 6, PM X 1187; loc. 17*a*, sample 77/2*, Ludford Lane, Ludlow, Shropshire; Upper Whitcliffe Formation; fragment showing cavity and posterior termination of Pa element; 3, lateral, and 6, oral views; ×120. 7, 10, PM X 1244; loc. 24*a*, sample 24*a*/2*a*, Prior's Frome, Hereford and Worcester; Upper Perton Beds; Pa element; 7, lateral, and 10, oral views; ×50. 8, 11, PM X 1160; loc. 7*a*, sample 7*a*/4, Aston Munslow, Shropshire; uppermost bed of Whitcliffe Formation; Pa element; 8, lateral, and 11, oral views; ×40. 9, 12, PM X 1189; loc. 18, sample 18/1, Ludford Corner, Ludlow, Shropshire; Upper Whitcliffe Formation; Pa element; 9, lateral, and 12, oral views; ×40.

Figs 13, 16. *Ozarkodina* cf. *snajdri*. PM X 1189; loc. 7*a*, sample 7*a*/1, Aston Munslow, Shropshire; Whitcliffe Formation; Pa element; 13, lateral, and 16, oral views; ×40.

Figs 14–15, 17–18. *Ozarkodina snajdri* (Walliser, 1964). 14, 17, PM X 1190; loc. 24*a*, sample 24*a*/2*a*, Prior's Frome, Hereford and Worcester; Upper Perton Beds; Pa element; 14, lateral, and 17, oral views; ×50. 15, 18, PM X 1191; loc. 33, sample 33/3, Brook House, Usk, Gwent; Upper Llangibby Beds; Pa element; 15, lateral, and 18, oral views; ×60.



MILLER, *Ozarkodina*

Downton to Onibury area

The Downton Bridge locality (14*a*) is no longer exposed, but collections made by Dr David J. Siveter in 1982 include *F. groenvalliana*, *L. arisaigensis* and non-palaeocope ostracodes from a bed immediately above the base of the Downton Castle Sandstone Formation. Like the basal bed of the Ludlow Bone Bed Member at Ludlow, carapaces of *F. groenvalliana* are present, although *N. verrucosa* is absent. The Downton Bone Bed (loc. 14*c*) within the Platyschisma Shale Member (Whitaker 1962) has yielded abraded conodonts, dominantly Pa elements of *O. confluens*, also elements of *C. dubius* with minor *O. excavata*, *O. r. eosteinhornensis* and *Oulodus* sp. At Onibury (loc. 12*a*) and Clungunford (locs 13*a*, 13*b*) *C. torosa* has been found in the Upper Whitcliffe Formation. Locality 12*b* at Onibury has yielded *L. fissurata* from the Downton Castle Sandstone Formation.

Weir Quarry, Downton. The ostracode fauna from the Upper Whitcliffe Formation is very sparse with only *H.* cf. *maccoyiana* and *C. torosa* present. No conodonts have been recovered. Ostracode faunas of the Downton Castle Sandstone Formation are very sparse reaching a maximum frequency of 0·2 ostracodes $m^2 \times 10^4$ but generally fewer than 0·1 ostracodes $m^2 \times 10^4$. Only three beds yielded more than ten ostracodes and these had very similar faunas of dominant *F. groenvalliana*, with rare specimens of *L. arisaigensis*, *L. fissurata* and non palaeocope ostracodes. The basal bone bed yielded a conodont fauna dominated by Pa elements of *O. confluens* with *C. dubius*, fragments of *Oulodus* sp. and two Pa elements of *O. excavata*.

Other localities

The base of the Downton Castle Sandstone Formation has been recognized at Kington (locs 19*a*–*b*) where multiple bone beds are developed in the Ludlow Bone Bed Member (Holland and Williams 1985). No conodonts and only a single specimen of *H.* cf. *maccoyiana* has been collected from the uppermost Upper Whitcliffe Formation (loc. 19*a*). A distinctive bed of limestone nodules in the Upper Whitcliffe Formation at Netherton (loc. 20) contains abundant *P. serratus*, *C. dubius*, *O. excavata*, *O. confluens*, a minor proportion of *P. recurvatus* and single specimens of *O. r. eosteinhornensis* and *Walliserodus* cf. *sancticlairi* (Pl. 1, fig. 18). The bed at the top of the formation contains *P. serratus*, *O. excavata* and large, abraded specimens of *O. confluens*. Only 0·32 m of the Downton Castle Sandstone Formation is exposed at Netherton and has yielded conodont collections consisting almost exclusively of *C. dubius* elements and a single Pa element of *O. confluens*. A single ostracode specimen of *F.* cf. *groenvalliana* has been collected by Dr David J. Siveter from the lowermost Downton Castle Sandstone Formation (Siveter 1989; Hansch *et al.* 1991).

SOUTHERN WELSH BORDERLAND INLIERS

Abberley and the Malverns

No localities in this area yielded abundant conodont or ostracode faunas in the present study. Material (BGS collections) has been examined and includes abundant examples of *C. torosa* from the Upper Ludlow Formation at Woodbury Quarry (loc. 21*c*). There are no examples of the *H. maccoyiana* material that Mitchell *et al.* (1962) indicated to be present. Exposures of the Whitcliffe Flags Member of the Upper Ludlow Formation around the village of Abberley (locs 21*a*–*b*, *d*) have also yielded specimens of *C. torosa*. At Brockhill Quarry (loc. 22), a single conodont sample from the Whitcliffe Flags Member yielded *O. excavata*, *C. dubius* and *O. confluens* in ascending order of abundance.

Woolhope inlier

Perton Lane. Non-palaeocope ostracodes have been recovered from the topmost Upper Perton Beds and a single specimen of *H.* cf. *maccoyiana* recovered from a coquina 0·06 m below the top of the beds. Two samples from locality 23*b*, 4 m below the top of the Upper Perton Beds contain *O. excavata*, *C. dubius*, *O. confluens* and *P. serratus*, also rare examples of *O. wimani*, *O. r. eosteinhornensis* and *O. snajdri* (Pl. 1). A sample 0·15 m below the top of the Upper Perton Beds contains only *C. dubius*, *O. confluens* and *O. excavata*.

Ostracode moulds from the Rushall Beds are stained rusty brown, occur almost exclusively in the coarse bases of fining-upwards beds and are poorly preserved due to the coarse nature of the sediment. Plant and eurypterid fragments are commonly associated and ostracode frequency is low, ranging from 0·02–0·18 $m^2 \times 10^4$. The lowermost 0·5 m of the Rushall Beds contains a relatively consistent ostracode fauna dominated by non-palaeocopes, together with approximately equal proportions of *Londinia* and *Frostiella*.

F. groenvalliana, *L. arisaigensis* and *L. fissurata* are present, with a specimen of *Nodibeyrichia* sp. recovered from a sample 0·15 m above the base of the Rushall Beds. 1·10 m above the base of the Rushall Beds the fauna is dominated by non-palaeocopes, with minor proportions (< 15 per cent.) of *Londinia* and *Frostiella*. Approximately 1·5 m above the base of the Rushall Beds the fauna consists of equal proportions of *Frostiella*, *Londinia*, and non-palaeocope ostracodes. The only carapace recovered from this section is that of *L. fissurata* from 1·5 m above the base of the Rushall Beds.

Prior's Frome. An old quarry face (loc. 24*a*) exposes 2·96 m of the Upper Perton Beds. Conodont faunas from the lower metre of the exposure are characterized by *O. excavata*, *C. dubius*, *O. confluens*, *P. serratus* and *P. recurvatus* in ascending order of abundance. A limestone bed 0·1 m thick, near the base of the exposure has also yielded *O. r. eosteinhornensis*, *O. r.* ssp. nov., *O. wimani*, and *O. crispa* (Pl. 3, fig. 5). Samples from the upper 2 m of the Upper Perton Beds contain an abundance of *Panderodus* elements, together with *C. dubius*, *O. excavata* and *O. confluens*. A single internal mould of *C. torosa* has been recovered from approximately 0·8 m below the top of the Upper Perton, Beds. The junction between the Rushall Beds and the underlying Upper Perton Beds is no longer exposed; the present exposure gap of 0·5 m has been estimated using a published photograph of the section (Gardiner 1927, pl. 39, text-fig. 2). Conodonts obtained from the Rushall Beds are fragmentary, abraded and consist dominantly of *C. dubius*; *O. confluens* is less common and *O. excavata*, *P. recurvatus* and *O.* cf. *snajdri* are rare.

Other localities. The BGS record bone beds from the base of the Rushall Beds, on the eastern margin of the Woolhope inlier at Caerswell Farm (loc. 25), Whittock's End Farm (loc. 26) and Rushall (loc. 27). *Calcaribeyrichia torosa* and non-palaeocopes have been recovered from the uppermost Upper Perton Beds at Rushall (loc. 27).

May Hill inlier

Localities in this area have not yielded abundant ostracode and conodont faunas for the present study. A single conodont sample from the Upper Longhope Beds of the Longhope by-pass road cut (loc. 30*b*) is dominated by Pa elements of *O. confluens*, together with elements of *O. excavata*, *C. dubius* and small numbers of *P. serratus* and *Oulodus* sp.

Tortworth inlier

Tite's Point. The Whitcliffe Formation directly overlies the Upper Leintwardine Formation and is marked at the base by an intraformational conglomerate. Only poorly preserved, often abraded and fragmentary conodont specimens have been recovered from the Whitcliffe Formation, ranging in frequency from sixty-one to 6961 elements per kg. The percentage of *C. dubius* elements gradually increases upwards through the formation; the percentage of *O. confluens* and *O. excavata* fluctuate greatly throughout the formation and show no regular pattern. All samples contain a predominance of Pa elements of *O. confluens* compared with other elements in its apparatus. One sample contains only the Pa elements of *O. confluens* and another contains twice as many Pa elements of *O. confluens* as the total of all the other elements of its apparatus. *Panderodus* elements are last present 7·5 m below the top of the Whitcliffe Formation. Rare taxa include *O. crispa*, which was found only in a sample 17 m below the top of the Whitcliffe Formation (Pl. 3, fig. 1). There are rare occurrences of *O. snajdri*, *O. r.* ssp. nov. and *O. r. remscheidensis*. Only 1·7 m of the Downton Castle Sandstone is exposed at Tite's Point, and has not yielded conodonts or ostracodes for the present study.

Other localities. The Brookend Borehole (loc. 32) covered the base of the Downton Castle Sandstone Formation (Cave and White 1968, 1978) but has not been sampled for the present study.

Usk inlier

The Upper Llangibby Beds and Speckled Grit Beds of the Usk area are distinct lithologically from the Upper Whitcliffe Formation and Downton Castle Sandstone Formation, respectively. The original lithostratigraphy of Walmsley (1959) has, therefore, been used for the present study rather than the mixture of lithostratigraphical units from Walmsley (1959) and from the Ludlow area (Bassett *et al.* 1982) as used by Barclay (1989) and Cocks *et al.* (1992).

Brook House. Three phosphatized internal moulds of the ostracode *H*. cf. *maccoyiana* have been recovered from conodont preparations from the Upper Llangibby Beds (loc. 33) and external moulds of *C. torosa* and *H*. cf. *maccoyiana* recovered by members of the Ludlow Research Group in 1992. Conodonts from the Upper Llangibby Beds are small, fragmentary and range in frequency from thirty-five to 236 elements per kg. Collections from the lower, more calcareous part of the exposure have similar faunas characterized by *C. dubius*, *O. confluens* and *O. excavata*. Less common species, also confined to the base of exposure, include *Oulodus* sp., *O. r.* ssp. nov. and *O. snajdri* (Pl. 3, fig. 15). The highest sample collected from approximately 3·5 m below the top of the Upper Llangibby Beds, contains only *C. dubius* and *O. confluens*. Approximately 0·4 m of the Speckled Grit Beds, exposed in a small overgrown bank on the south side of the lane to the west of the bridge, have yielded *O. confluens* and *C. dubius*.

Other localities. Localities at Llandegveth Church (loc. 34*a*), Llangybi Castle (loc. 34*b*), Granary Farm (loc. 34*c*) and Llanddewi Court (loc. 34*d*) previously displayed Speckled Grit Beds with fragmentary fish remains (Walmsley 1959) but none of these is now exposed. The base of the Raglan Mudstone Formation in the Rumney Borehole (loc. 35) is marked by a 0·06 m bed containing abundant fish remains and shell fragments, a level taken to correlate with the Ludlow Bone Bed (Waters and White 1978).

EAST CENTRAL AND SOUTHWEST WALES

Long Mountain

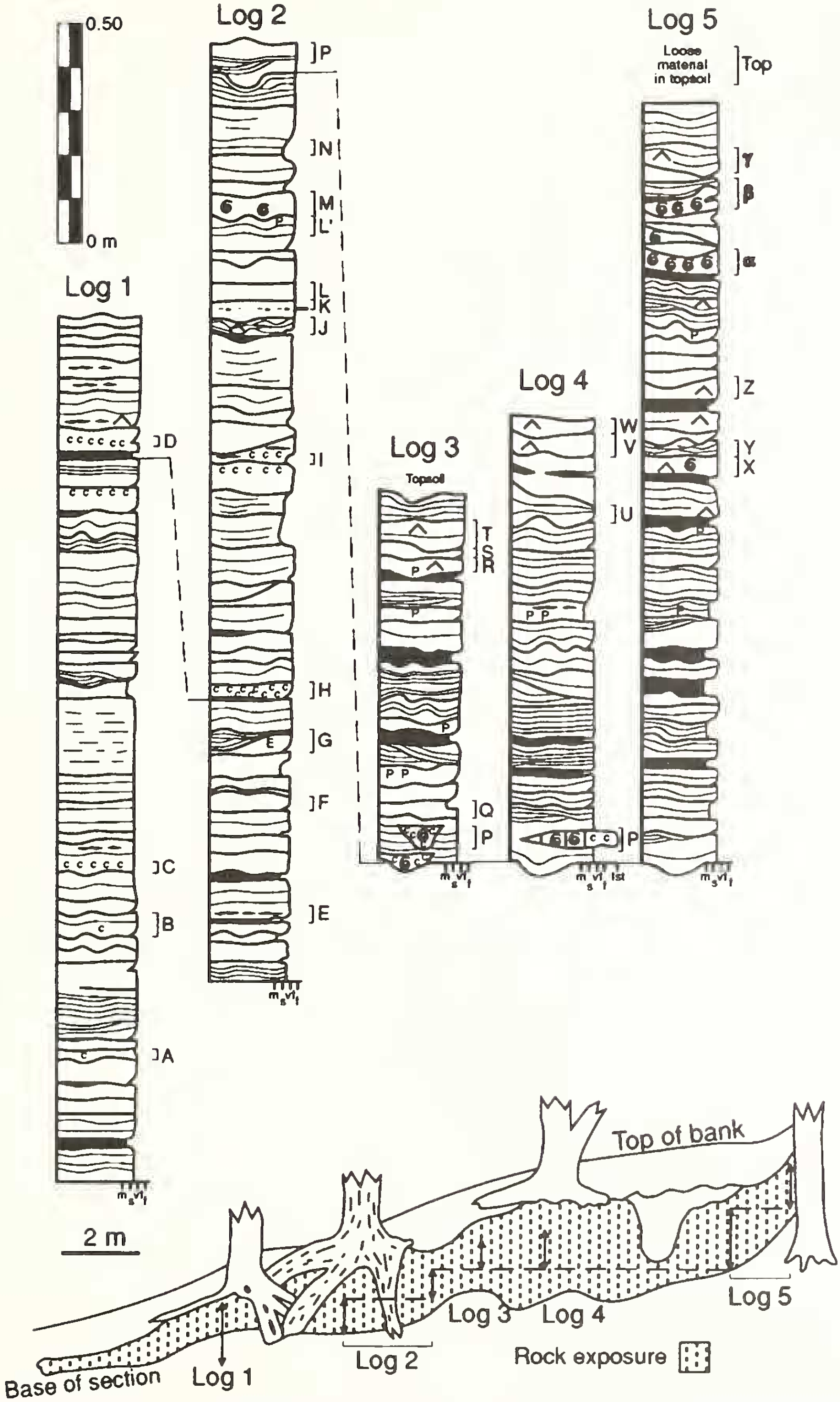
In the Long Mountain area the base of the Downton Castle Sandstone Formation cannot be distinguished lithologically, but correlates with a level within the upper part of the Wallop Hall Member of the Causemountain Formation (Palmer 1970, 1973).

Wallop Hall. 4·75 m of the Wallop Hall Member, Causemountain Formation are exposed, showing a gradual transition in macrofauna from parallel laminated siltstones, rich in articulate brachiopods, below a thin bone bed (bed K) to very fine sandstones characterized by gastropods, inarticulate brachiopods and plant fragments above the bone bed (Text-fig. 11). Ostracodes, preserved only as moulds of disarticulated valves, range in frequency from 0·01 to 1·35 ostracodes $m^2 \times 10^4$ (Text-fig. 12). Most ostracode specimens have been collected above the bone bed (bed K); faunas below that level are sparse (Text-fig. 12). Ostracode specimens below the bone bed are predominantly *C. torosa* with rare *H*. cf. *maccoyiana* and *L*. cf. *scanensis*; all three species are also present above the bone bed, and last appear within bed M (Text-fig. 12). *Londinia arisaigensis* and *L. fissurata* first occur just below the bone bed. On the bedding plane surface of the bone bed (Bed K), *C. torosa*, *Lophoctenella* sp., *N. verrucosa*, *L. arisaigensis*, *L. fissurata*, *F. groenvalliana*, and non-palaeocope ostracodes are present. 0–0·25 m above the bone bed the fauna is dominated by *Londinia* with minor proportions of *Nodibeyrichia*, *Frostiella* and non-palaeocopes. Beds 3P and 3Q contain abundant *Londinia*, but the other ostracode collections from beds more than 0·25 m above the bone bed are dominated by non-palaeocopes with minor *Londinia*, *Nodibeyrichia* and *Frostiella*. Eight well-preserved *C. dubius* conodont elements have been recovered from bed K.

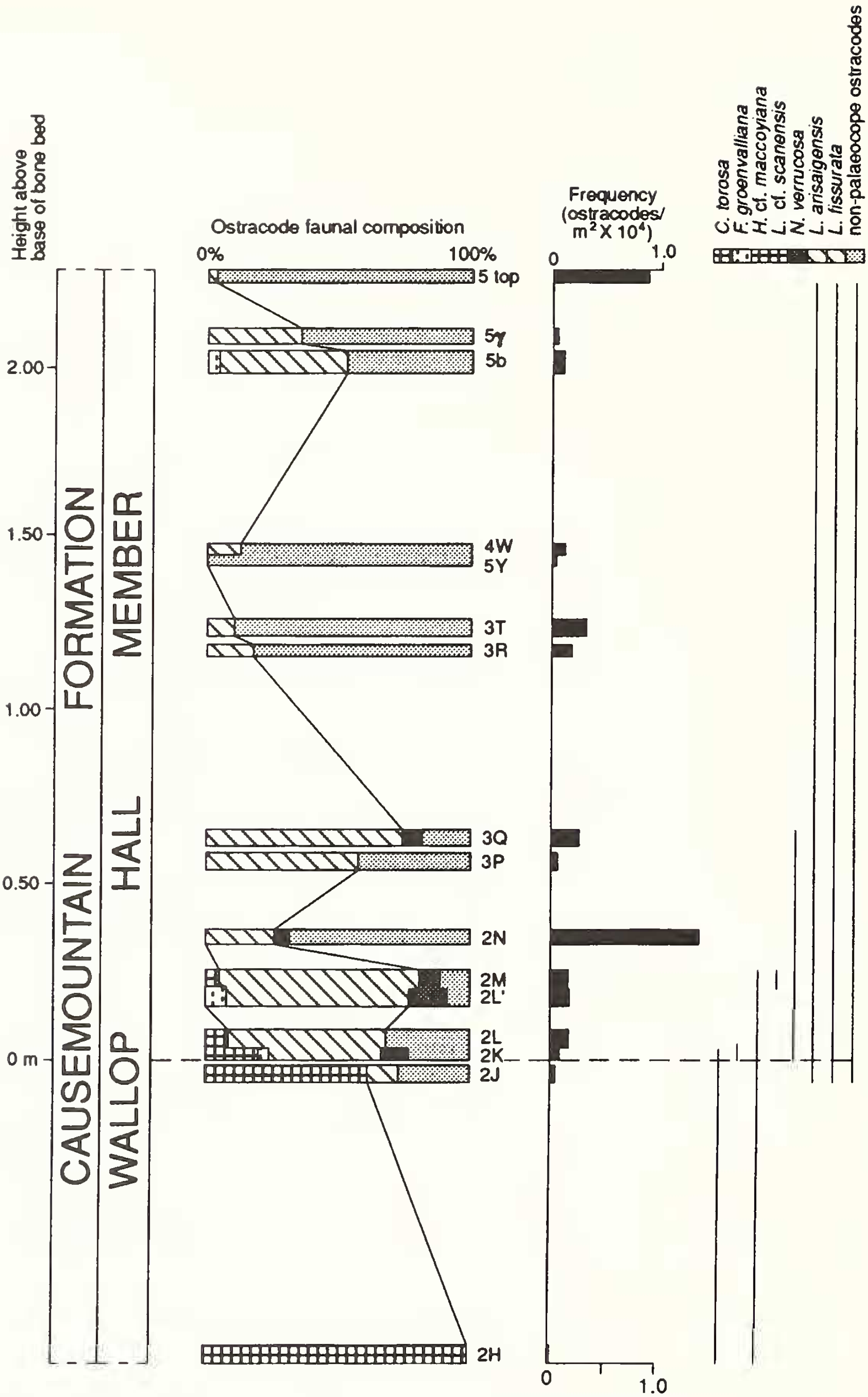
Clun to Felindre area

Nantyrhynau Quarry. This locality (loc. 37) was discovered in 1986 by the BGS during field mapping for the Montgomery Sheet. The field report stated that the boundary between the Cefn Einion and Clun Forest formations was exposed within the quarry, at the base of a calcareous bed approximately 2·5 m below the top of the section. The calcareous bed yielded two *O. excavata* Pa elements and the ostracodes *C. torosa*, *H*. cf. *maccoyiana*, *Lophoctenella* sp., *L. arisaigensis*, *L. fissurata* and *Frostiella* sp.

Other localities. A section through the Clun Forest Formation was recently exposed when a new forestry path was cut at Within's Wood (loc. 39*a*). A well developed bone bed is present and is followed by a succession of eight, one millimetre thick bone beds. *F. groenvalliana*, non-palaeocope ostracodes and a specimen of *Londinia* sp. have been recovered from a rottenstone below the level of the bone beds. Abraded conodont elements of *O. confluens* and *C. dubius* have been recovered from the well developed bone bed which yielded 216 conodont elements per kg. Localities in the vicinity of Felindre at Medwaledd Brook (loc. 38*a*) and Stonehouse Dingle (loc. 38*b*), provide discontinuous exposures through the uppermost Cefn Einion Formation and the lowermost Clun Forest Formation (Earp 1938, 1940), but provided no conodont or ostracode material for the present



TEXT-FIG. 11. Measured logs of the Wallop Hall Member, Causemountain Formation at Wallop Hall, Long Mountain (loc. 36*a*), showing sampled horizons (A–Z, α–γ) and sketch of the exposure showing position of logged sections.



TEXT-FIG. 12. Ostracode faunal composition, frequency and ranges of species from the Wallop Hall Member, Causemountain Formation at Wallop Hall, Long Mountain (loc. 36*a*). Only samples with ten or more valves present are included.

study. A locality at Hendre Farm (loc. 38*c*) has yielded *H.* cf. *maccoyiana* (Pl. 2, fig. 1) and *L. arisaigensis* from the Cefn Einion Formation. A forestry cutting in the Clun Forest (loc. 39*b*) has yielded *L. arisaigensis*, *L. fissurata*, non-palaeocope ostracodes, and *Leperditia* sp. from a lithology similar to the Green Downton Formation of Holland (1959). *Calcaribeyrichia torosa* has been recovered from the Cefn Einion Formation at Bryn (loc. 39*c*) and Hurst Mill (loc. 39*d*).

Knighton

Meeting House Lane. Collections made by Dr David J. Siveter from the *Platyschisma helicites* Beds are described herein as the locality (40*c*) is no longer exposed. No conodont or ostracode faunas have been found from the Llan-wen Hill Beds at this locality. The lowermost bed of the *Platyschisma helicites* Beds contains *C. torosa*, *H.* cf. *maccoyiana*, *L. arisaigensis*, *L. fissurata* and abundant non-palaeocope ostracodes. Higher in the *P. helicites* Beds, *L. arisaigensis*, *L. fissurata*, and two specimens of *Frostiella* sp. have been obtained. The Green Downton Formation contains *L. arisaigensis* and *L. fissurata*.

Other localities. Collections made by Dr David J. Siveter from the now overgrown *P. helicites* Beds at Middle Pitts Cottages (loc. 40*b*) include *L. arisaigensis*, *N. verrucosa*, and non-palaeocope ostracodes.

Southwest Wales

The unconformable base of the Downton Group, progressively oversteps older and more deformed rocks in a westerly direction, until west of Llandeilo the Downton Group overlies Ordovician strata (Potter and Price 1965; Squirrell and White 1978; Bassett 1982). Localities reported to expose this unconformity at Builth Wells (loc. 41), Cwm Graig Ddu (loc. 42) and the Sawdde Gorge area (locs 44*a*–*c*) have yielded no conodont or ostracode faunas for the present study.

Capel Horeb Quarry. No conodont or ostracode specimens have been recovered from the Upper Roman Camp Formation, a correlative of the Lower Whitcliffe Formation (Potter and Price 1965). *F. groenvalliana* and non-palaeocope ostracodes have been recovered from the Long Quarry Formation. The conodont specimen reported by Aldridge (1985) as *O. r. eosteinhornensis* has been re-examined and identified by the present author as a fragment of *O. confluens*. *Coryssognathus dubius*, *O. excavata*, and *P. serratus* also occur in the same sample.

Cennen Valley. In the road cut (loc. 45*a*), the Long Quarry Formation overlies unconformably the Cennen Formation (Potter and Price 1965; Squirrell and White 1978, text-fig. 2b; Bassett 1982; Siveter *et al.* 1989), but the section is now completely overgrown. Authors have used differing lithostratigraphical nomenclature, but the stratigraphy employed by Siveter *et al.* (1989) is adopted herein. A thickness of 3·55 m of the Cennen Formation rests unconformably on the older Trichrûg Formation (a full list of macrofauna is given in Squirrell and White 1978, table 3). Ostracodes were identified by the author (BGS collections) as *F.* cf. *groenvalliana*, *L.* cf. *scanensis*, and *C. torosa*. Conodont samples collected by Dr R. J. Aldridge when the section was fully exposed, proved to be barren. *F. groenvalliana* and *H.* cf. *maccoyiana* have been recorded 9·83 m above the base of the overlying Long Quarry Formation (Squirrell and White 1978, table 3).

PALAEOENVIRONMENTS

Upper Whitcliffe Formation and lateral equivalents

Watkins (1979) and Bassett *et al.* (1982) interpreted deposition as subtidal on a proximal shelf, mostly within wave base, shallowing towards the top of the formation with coquinas representing storm events. Allen (1985, p. 90) also recognized storm-related planar to hummocky lamination, cross-lamination and current ripples. Conversely, Richardson and Rasul (1990) proposed a deepening towards the end of deposition of the Upper Whitcliffe Formation at Downton (loc. 14*b*), based on palynofacies. The thickness of upper Ludlow strata is much greater in east central Wales than on the shelf and probably reflects subsidence of the outer shelf and shelf margin of the Welsh Basin (Bassett *et al.* 1982). Palynofacies at Downton, Long Mountain and at Knighton all show a change towards more open sea floras towards the top of the Ludlow Series (Richardson and Rasul 1990). Sedimentological evidence suggests a shallowing stratigraphically upwards through the Llanwen Hill Beds at Knighton (Holland 1959, p. 475). The Ludlow Series in south-west Wales, traditionally regarded as part of the basinal facies of the Welsh Basin (Holland 1962, text-fig. 1), has also been described as a sandy shelf facies (Potter and Price 1965). A proximal land area probably existed to the south during deposition of the Upper Roman Camp Formation at Capel Horeb, from which plant debris drifted into a shallow sea (Siveter *et al.* 1989, p. 97). The depositional environment of the Cennen Formation near Llandeilo has been interpreted as very shallow marine (Squirrell and White 1978). Breaks in the succession occur near the top of the Ludlow Series in the Cennen Valley, but the succession is continuous at the Sawdde Gorge (Squirrell and White 1978). The apparent 'early' occurrence of *F. groenvalliana* in the Cennen Formation of the Cennen Valley was attributed to 'occurrence in this area in late Ludlow times of a lithofacies comparable with that of the Downton Series' (Squirrell and White 1978, p. 9).

The composition of conodont samples that have undergone significant post-mortem sorting reflect the hydrodynamic regime, rather than the original faunal composition (McGoff 1991). It seems unlikely that samples from the base of the Upper Whitcliffe Formation at Ludlow (loc. 15) have undergone significant post-mortem sorting, as elements are well preserved and relative proportions of individual elements of *O. excavata* remain almost constant, thus reflecting original apparatus composition (Text-fig. 8). Elements from the uppermost metre of the Upper Whitcliffe Formation contain a dominance of *C. dubius* and *O. confluens*, often present almost exclusively as abraded specimens of Sa/Sb and Pa elements respectively. Post-mortem sorting seems to have significantly affected these samples as the Sa/Sb and Pa elements of the respective species are the most robust in the apparatus and therefore most likely to withstand the abrasion associated with sorting. Conodont faunal variations (Text-fig. 7) probably reflect a combination of changes in faunal abundances and hydrodynamic regimes. The preservation of the conodont fauna indicates a more turbulent environment towards the top of the Upper Whitcliffe Formation compared with the basal 5 m. This increased turbulence could be associated with the shallowing interpreted by Watkins (1979) and Bassett *et al.* (1982). General trends in conodont faunal composition towards the top of the Ludlow Series are similar at Aston Munslow (loc. 7*a*), Woolhope (locs 23–24) and Usk (loc. 33) and may also indicate shallowing. The fauna from the topmost bed of the Whitcliffe Formation at Aston Munslow, dominated by *C. dubius* with minor proportions of *O. confluens*, *O. snajdri*, and *O.* cf. *crispa*, is almost directly comparable with that from sample 18/1, 0·1–0·15 m below the top of the Upper Whitcliffe Formation at Ludford Corner, Ludlow (loc. 18), differing only in the absence of *remscheidensis* plexus elements.

Conodont elements from the Upper Longhope Beds at Longhope (loc. 30*b*) and throughout the Whitcliffe Formation at Tite's Point (loc. 31*b*) have probably undergone significant sorting; the collections are dominated by abraded Pa elements of *O. confluens*. Abrasion and winnowing indicate that, compared with the rest of the shelf, a more turbulent environment existed in this area during deposition of the Whitcliffe Formation.

Downton Castle Sandstone Formation

The marked sedimentological, macro- and microfaunal change at the base of the Ludlow Bone Bed Member has been explained by a sudden regression and subsequent transgression (Allen and Tarlo 1963; Allen 1974; Antia and Whitaker 1978; Antia 1979*a*, 1980; Bassett *et al.* 1982; Richardson and Rasul 1990). Smith and Ainsworth (1989, p. 898) explained the deposition of the Ludlow Bone Bed Member by 'repeated storm reworking during a period of reduced sediment supply, probably associated with a raised sea level'. Hummocky cross-stratification has been documented from the Sandstone Member at Ludford Corner and suggests shallow deposition (water depths of a few metres), possibly in a shoreface environment dominated by storms (Siveter *et al.* 1989; Smith and Ainsworth 1989). Richardson and Rasul (1990) stated that the lowermost Downton Castle Sandstone Formation at Ludlow contains a greater proportion of land-derived sporomorphs than the coeval section at Weir Quarry, Downton, although Ainsworth (1991) noted that these differences could be explained by preferential winnowing of the smaller acritarchs from the larger spores. Richardson and Rasul (1990, p. 681) suggested that distribution patterns could have been affected by a 'pattern of distributionary channels delivering high concentrations of land-derived sporomorphs in a non-uniform fashion along an irregularly prograding shoreline'. Ainsworth (1991) questioned Richardson and Rasul's (1990) palynofacies interpretations suggesting that more recent sedimentological interpretations (Smith and Ainsworth 1989) indicated storm dominated environments in which onshore and offshore sediment movements probably influenced proportions of microplankton and spores. Jeram *et al.* (1990) documented trigonotarbid arachnids from the Ludlow Bone Bed Member at Ludford Corner (loc. 18), which are the earliest reported undoubted land animals and indicate a proximal land area. Localized variations of lithofacies at the base of the Rushall Beds in the Woolhope inlier have been proposed to indicate shoals in a shallow sea (Gardiner 1927). The bone bed at the base of the Rushall Beds has been interpreted as a lag concentrate formed during marine regression, and the Rushall Beds interpreted as a marginal marine deposit on a prograding sandy shore which is succeeded by subtidal mud flats (Allen 1985; Brandon 1989). The *Platyschisma helicites* Beds in the basin at Knighton have no basal bone bed and are thicker than the equivalent Platyschisma Shale Member on the shelf at Ludlow, suggesting continuous deposition in the basinal region (Bassett *et al.* 1982; Allen 1985). Palynofacies variations at Wallop Hall (loc. 36*a*) indicate a gradual change to more inshore environments between the late Ludlow and the early Přídolí, followed by a gradual change to a more offshore setting and a subsequent return of more onshore conditions (Richardson and Rasul 1990). A similar but less pronounced palynofacies curve has been documented at Knighton (Richardson and Rasul 1990). Concentrations of the inarticulate brachiopod *C. implicata* at the top of the Upper Llan-wen Hill Beds at Knighton (locs 40*a*, *c*), also provide an environmental link with similar beds in the uppermost Upper Whitcliffe Formation at Downton (loc. 14*a*) and Kington (locs 19*a*, *b*) (Holland 1962, 1988).

By the end of the Silurian, 'ostracodes had occupied most of the marine environments and taken up most of the life-styles known from modern ostracodes' (Siveter 1984, p. 71). Based on evidence from elsewhere in Europe and also in North America, Siveter (1984, p. 73) suggested that in the marine to restricted marine transition of the British Downton Group that ostracodes 'for the first time began adapting to salinity changes that included reduced salinity, brackish water, and hypersaline conditions'. The species present in the Upper Whitcliffe and Downton Castle Sandstone formations cannot be directly compared taxonomically with Recent ostracodes. However, to assess their palaeoenvironmental and biostratigraphical potential, one can compare other reported occurrences of the same late Silurian species.

Frostiella groenvalliana has been reported in a wide range of environments (Hansch *et al.* 1991), from the deeper water, outer shelf areas of the Łeba elevation, Poland (Tomczykowa and Witwicka 1974) and the Kaliningrad region, Estonia (Kaljo and Sarv 1976) to fully marine carbonate facies of Scånia, Sweden (Martinsson 1962, 1963, 1967). Sarv (1968, 1971) and Kaljo and Sarv (1966) demonstrated the incoming of *F. groenvalliana* within a fully marine succession in the east Baltic. *F. groenvalliana* has been reported from basal part of the Downton Castle Sandstone Formation in the basinal area of the Welsh Basin at Clun, Knighton and Long Mountain (Shaw 1969; present study), across the 'shelf' area of Shropshire (Shaw 1969; Siveter 1974, 1978, 1988, 1989; White and Coppack 1978; Hansch *et al.* 1991; present study), at Woolhope and Capel Horeb, Llandovery (present study) and in the Scout Hill Flags of the Lake District (Shaw 1971). Because of its apparently wide facies tolerance, the sudden appearance of *F. groenvalliana* at the base of the Ludlow Bone Bed Member is therefore unlikely to be influenced entirely by a marked facies change at that level.

Londinia arisaigensis has been reported from Arisaig, Nova Scotia from both limestones and shales (Copeland 1960, 1964). In the Welsh Basin *L. arisaigensis* has been recovered from the Downton Castle Sandstone Formation and its lateral equivalents across the 'shelf' area throughout Shropshire and at Woolhope and from the 'basinal' area at Long Mountain and Knighton (Shaw 1969; Siveter 1974, 1978, 1989; present study). The same species has been recovered also from the Cefn Einion Formation at Clun (present study) and the Causemountain Formation at Long Mountain (Shaw 1969), and therefore appears to have been tolerant of a wide range of environments. *L. fissurata* has been reported only from the Welsh Basin (Shaw 1969; Siveter 1974, 1978, 1989) commonly associated with *L. arisaigensis* (present study).

Nodibeyrichia verrucosa is considered by Hansch and Siveter (1994) to be conspecific with *Nodibeyrichia jurassica* (Gailite, 1967) the index species for the late Přídolí Ohessare 'Stage' of Saaremaa, Estonia; it is commonly found in faunally rich and diverse open shelf, marine environments (Sarv 1968, 1971; Kaljo 1970; Meidla and Sarv 1990; Nestor 1990; Hansch and Siveter 1994). In the Welsh Borderland, *N. verrucosa* is restricted to the Much Wenlock, Ludlow, Downton, Knighton and Long Mountain areas (Shaw 1969; Siveter 1974, 1978; present study), areas which embrace both the shelf and basin areas of the Welsh Borderland.

Calcaribeyrichia torosa, the characteristic ostracode of the Upper Whitcliffe Formation in the Welsh Borderland, is found in the lateral equivalent to the Downton Castle Sandstone Formation at Long Mountain (Shaw 1969; present study) and on the shelf at Ludlow (Bassett *et al.* 1982). It is also present in the Underbarrow, Kirkby Moor, and Scout Hill Flags of Cumbria (Shaw 1971). *Beyrichia cuspidata* (Grönwall, 1867), a species characteristic of the marine upper Ludlow of Scånia, has been noted as a possible synonym for *C. torosa* (Siveter 1989).

The ostracode taxa characteristic of the Upper Whitcliffe and Downton Castle Sandstone formations appear to be tolerant across a wide range of environments; the marked turnover in ostracode faunas at the base of the Ludlow Bone Bed Member is, therefore, unlikely to be entirely facies related. In the more offshore basinal area of the Welsh Borderland at Long Mountain, the ostracode faunal change is not as sudden as at Ludlow (Shaw 1969; Text-fig. 12). This gradual ostracode faunal change is consistent with coeval gradual palynofacies changes (Richardson and Rasul 1990). The abundance of some ostracode taxa, for example *C. torosa*, therefore appears to be partly environmentally controlled. Changes in ostracode frequencies, preservation, and faunal compositions (Text-figs 9–10) are coeval with fine scale sedimentological changes in the Ludford Lane section, and these factors are possibly related.

The ostracode faunas from the Rushall Beds at Perton Lane (loc. 23*a*) are concentrated in the coarse bases to fining upwards units. Smith and Ainsworth (1989) proposed that similar beds in the basal metre of the Platyschisma Shale Member at Ludlow were the products of storms; therefore, it is possible that the ostracodes at Perton were selectively winnowed and concentrated by storm action.

Local factors also appear to affect the presence and frequency of ostracode faunas in the Downton Castle Sandstone Formation, which at Downton (loc. 14*b*) contains a very sparse ostracode fauna compared with Ludford Corner, only 5·5 km to the east, when sedimentological evidence (present study) does not suggest vast differences in lithofacies. The sedimentology of the Downton Castle Sandstone Formation, which yields very few ostracodes, at Aston Munslow is distinct from coeval levels at Ludford Lane, as the sediment coarsens upwards much more rapidly, and lacks multiple bone beds in the lowermost 0·3 m. The Rushall Beds at Perton Lane (loc. 23) are characterized by plant-rich fine sandstones and siltstones with ostracodes, while at Prior's Frome (loc. 24), only 2·5 km to the SE, they comprise conglomerates, very fine sandstones and mudstones but lack ostracodes. Ostracodes are common at localities characterized by an abundance of land plant fragments and/or land derived sporomorphs, for example the Rushall Beds at Perton (loc. 23*a*) and the Downton Castle Sandstone Formation at Ludford Lane (loc. 17). This may explain why the Downton Castle Sandstone Formation at Downton (loc. 14*b*), with a lower percentage of land derived sporomorphs compared with Ludford Lane (Richardson and Rasul 1990) also contains a rather sparse ostracode fauna. It is, therefore, possible that high percentages of palynomorphs, land plant fragments, and ostracodes are related phenomena. High frequencies of land-derived sporomorphs could have been the result of proximal distributary channels delivering sediment along an irregularly prograding shoreline (Richardson and Rasul 1990).

Ostracode faunas recovered from a limestone bed at Linley Brook (loc. 3*b*) are very similar to faunas from beds 17*a*/28 and 17*b*/24 in the Platyschisma Shale Member at Ludlow (Text-figs 9–10). Ostracode collections from these limestone beds are also similar to collections from the Downton Castle Sandstone Formation at Willey (White and Coppack 1978). It is, therefore, possible that the Much Wenlock and Ludlow areas experienced similar environmental conditions at the time of deposition of the Downton Castle Sandstone Formation. However, unabraded conodont specimens recovered from one of these limestone beds at Linley Brook (loc. 3*b*) are unusual, as conodont specimens recovered from the Downton Castle Sandstone Formation across the Welsh Borderland are usually heavily abraded (Pl. 1, fig. 11); the possibility that these abraded specimens have been transported or reworked from older strata cannot be discounted. These calcareous beds with well preserved conodont elements suggest a marine environment in the Much Wenlock area in which conodonts of the genera *Oulodus* and *Ozarkodina* existed during deposition of the Downton Castle Sandstone Formation. Original calcareous ostracode valves obtained from these beds are unusual as ostracodes are only present at these levels elsewhere in the Welsh Borderland as decalcified moulds.

Leperditiid ostracodes are often regarded as shallow water restricted forms (Siveter 1984). *Leperditia* sp. occurs within the Green Downton Formation at Clun (loc. 39*b*) and in a glacial erratic from the Vale of Wigmore, which suggests that by late Downton times the Welsh Basin had become so restricted that only leperditiid ostracodes together with inarticulate brachiopods such as *Lingula* sp. could exist. A single specimen of *Leperditia* sp. has been recovered from loose material from the Platyschisma Shale Member of the Downton Castle Sandstone Formation at Ludford Lane (Pl. 2, fig. 18).

CORRELATION

Britain

The base of the Ludlow Bone Bed at Ludford Corner (loc. 18) defines the base of the Downton Group (Holland *et al.* 1963), formerly regarded as the base of the Downtonian Stage. At the stratotype section (loc. 18) this horizon is marked by the onset of vertebrate sand deposition which has been used to correlate this lithostratigraphical level across the Welsh Borderland to Much Wenlock (Robertson 1927; White and Coppack 1978), Corve Dale (Shergold and Shirley 1968), Downton (Whitaker 1962), Netherton (Stamp 1923; Ball 1951), Kington (Holland and Williams 1985), the Malvern-Abberley Hills (Phipps and Reeve 1967), Woolhope (Squirrell and Tucker 1960), May Hill and Gorsley (Lawson 1954, 1955), Tite's Point (Cave and White 1971), Usk (Walmsley 1959) and Cardiff (Waters and White 1978). Bone beds are developed within the Platyschisma Shale Member of the Downton Castle Sandstone Formation, at Weir Quarry Downton (loc. 14*b*) and Ludford Lane (Text-fig. 6); although they are not as well developed as the Downton Bone Bed (loc. 14*c*; Whitaker 1962), they are possible correlatives. In the absence of a basal bone bed, Antia (1979*b*) used the first occurrence of *F. groenvalliana* and the disappearance of distinctive Upper Whitcliffe brachiopods to indicate the local base of the Downton Castle Sandstone Formation at Siefton (loc. 10*b*). Bone beds at the base of the Downton Castle Sandstone Formation and its lateral equivalents across the shelf area rarely extend laterally into coeval successions in east central Wales (Straw 1930). Only at Wallop Hall, Long Mountain (loc. 36*a*) is a thin bone bed developed at a comparable level within the Causemountain Formation (Palmer 1973). The ostracode succession of *Neobeyrichia lauensis* (Kiesow, 1888) –*C. torosa* –*F. groenvalliana* –*Leperditia* sp. has been recognized in the Ludlow and Přídolí Series of Shropshire and east central Wales, and used for correlation (Straw 1930; Shaw 1969; Siveter 1978, 1989). Other correlations of the base of the Downton Castle Sandstone Formation into east central Wales are based on macrofaunas. For example, the basal *Platyschisma helicites* Beds at Knighton (the local equivalent to the Downton Castle Sandstone Formation) have a similar lithology to the underlying Upper Llan-wen Hill Beds, but can still be identified on the basis of a faunal change from articulate brachiopod-dominated faunas to gastropod, bivalve and inarticulate brachiopod faunas (Holland 1959, 1962). Similar faunal successions have been described from the area around Clun and Kerry (Earp 1938, 1940).

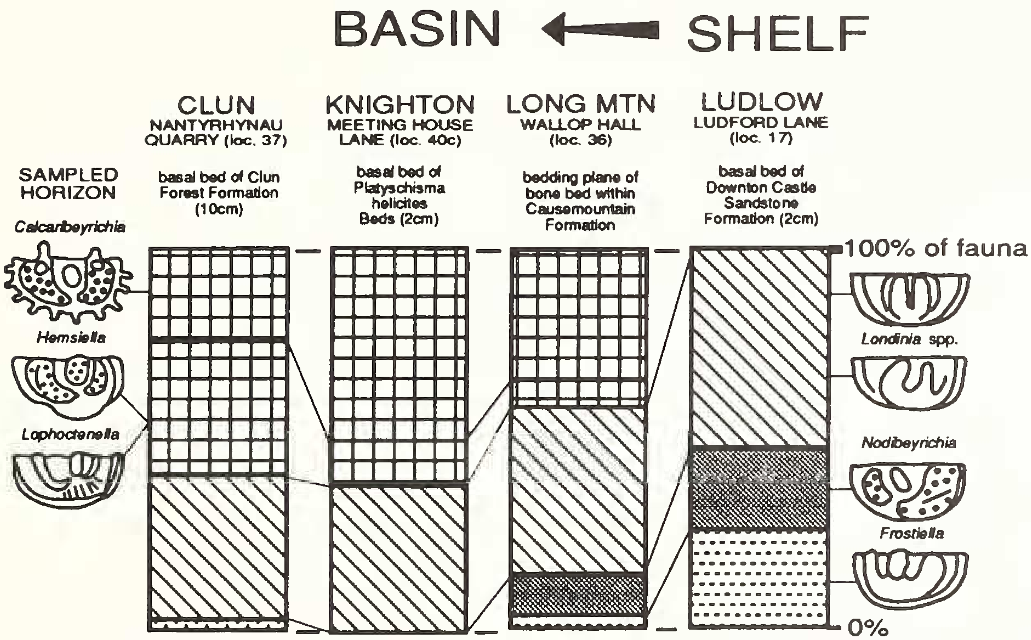
The base of the Downton Castle Sandstone Formation at Ludlow is coincident with changes in the macro- and microfaunas (Bassett *et al.* 1982, text-fig. 6). The microfaunal changes displayed by the ostracode faunas offer a potential for biostratigraphical correlation of the base of the Downton Group in Britain. As discussed above, this changeover in ostracode fauna is unlikely to be entirely due to the facies change at this level as these species are known elsewhere in a wide range of environments.

Calcaribeyrichia torosa appears to be environmentally controlled (see above) and it cannot be used as a definitive indicator of Ludlow strata within Britain. *L. arisaigensis*, although common in the Downton Castle Sandstone Formation, has been recovered at Clun and Long Mountain during the present study from levels taken by Cocks *et al.* (1992) to correlate with the Upper Whitcliffe Formation, and thus possibly has only limited correlation potential. *L. fissurata* is confined to the Downton Castle Sandstone Formation (and its lateral equivalents) and could prove biostratigraphically useful. *Nodibeyrichia verrucosa* is restricted to the lowermost 0·34 m of the Downton Castle Sandstone Formation at Ludlow, and therefore has potential for correlation with other areas of the Welsh Borderland. *F. groenvalliana* is more abundant than *N. verrucosa* and is geographically more widespread. In Britain it is widespread at the base of the Downton Castle Sandstone Formation and its lateral equivalents (see above) and can, therefore, be used to indicate basal Downton strata across the Welsh Borderland and into the Lake District.

The only potential anomaly in an otherwise consistent scheme in Britain is the reported occurrence of *F. groenvalliana* in the Cennen Beds (?uppermost Ludlow) of the Cennen Valley, Wales (Squirrell and White 1978; Bassett *et al.* 1982; Siveter 1989). The presumed Ludlow age for the Cennen Formation is based on the occurrence of the characteristic Ludlow trilobite *Calymene neointermedia* and the brachiopod *Sphaerirhynchia* cf. *wilsoni* in the lower part of the Cennen Beds (Squirrell and White 1978). However, most species in the Cennen Formation, including the characteristic Upper Leintwardine brachiopod *Hyattidina canalis*, also occur in the Tilestones (Long Quarry Formation) (Squirrell and White 1978, table 3). The Cennen Valley section is no longer exposed, although the author has examined material at the BGS (Keyworth). The specimens of *Frostiella* are not well preserved and are almost exclusively internal moulds. Well preserved external moulds are needed for positive identification and the specimens are here considered to be best referred to *F.* cf. *groenvalliana*. The species itself is not lithofacies related, so it is unlikely that a lithofacies comparable with the Downton Group could account for the occurrence of it in the Cennen Formation of the Cennen Valley in late Ludlow times (cf. Squirrell and White 1978, p. 9). The ostracodes *Lophoctenella* cf *scanensis* and *C. torosa* are also present but do not unequivocally indicate a Ludlow age (see earlier discussion). The uppermost Ludlow age for the Cennen Beds is therefore unproven, and *F. groenvalliana* is here considered restricted to the Downton Group of Britain until the Cennen Beds can be shown to be unequivocally Ludlow in age. The upper and lower contacts of the Cennen Formation are uncomfortable, and it is possible that it is a local unit at the base of the Downton Group.

Frostiella groenvalliana does not always occur immediately at the base of the Downton Castle Sandstone Formation as at Linley (locs 3*a*–*c*), Brockton (loc. 5), Culmington (loc. 11), Downton (loc. 14*b*), Clun (loc. 39*a*) and Llandovery (loc. 43). Without detailed bed by bed collections, the assumption that the base of the Downton Castle Sandstone Formation is at the level of the first occurrence of *F. groenvalliana* at Siefton (Antia 1979*b*) is therefore unsubstantiated. 'The fauna below does contain some species (e.g. *Lingula minima* and *L. kiesowi*) which are commonly found in the Downtonian' (Antia 1979*b*, p. 127) which suggests that the base of the Downton Castle Sandstone Formation at Siefton is possibly at a level below the first occurrence of *F. groenvalliana*.

The first occurrence of *F. groenvalliana* at Wallop Hall is coincident with a thin (1 mm) bone bed within the Causemountain Formation (Text-figs 11–12). Closely spaced ostracode samples across this level show a gradual change from a fauna similar to that of the Upper Whitcliffe Formation at Ludlow to a fauna comparable with that of the Downton Castle Sandstone Formation (Text-fig. 9). *Nodibeyrichia verrucosa* is confined to the lowermost 0·34 m of the Downton Castle Sandstone Formation at Ludlow and first occurs (with *F. groenvalliana*) at the base of bed K, at Wallop Hall (Text-fig. 12). On this basis, the base of the Downton Castle Sandstone Formation should be correlated with the base of bed K within the Causemountain Formation at Wallop Hall (loc. 36*a*). Similar ostracode faunas from assumed basal Přídolí horizons at Knighton (locs 40*b*–*c*), and Nantyrhynau Quarry, Clun (loc. 37) offer potential for correlation of the base of the Downton Castle Sandstone Formation from the shelf at Ludlow to the westernmost part of the Ludlow outcrop (Text-fig. 13).



TEXT-FIG. 13. Comparison of ostracode faunas from individual beds at assumed basal Přídolí horizons along a shelf-basin transect of the Welsh Basin.

The bone beds at Within's Wood (loc. 39*c*) occur above the first occurrence of *F. groenvalliana*, indicating that these bone beds correlate above the base of the Downton Group and within the Clun Forest Formation. The bone beds are possible correlatives of similar bone beds in the Clun Forest Formation at Bishop's Castle (Allender 1958; Allender *et al.* 1960), the *Platyschisma helicites* Beds at Meeting House Lane at Knighton (loc. 40*c*), and the Platyschisma Shale Member at Downton (loc. 14*c*). Conodonts recovered from the lowermost bone bed at Within's Wood (loc. 39*c*) are also similar to conodont collections from the Downton Bone Bed (loc. 14*c*).

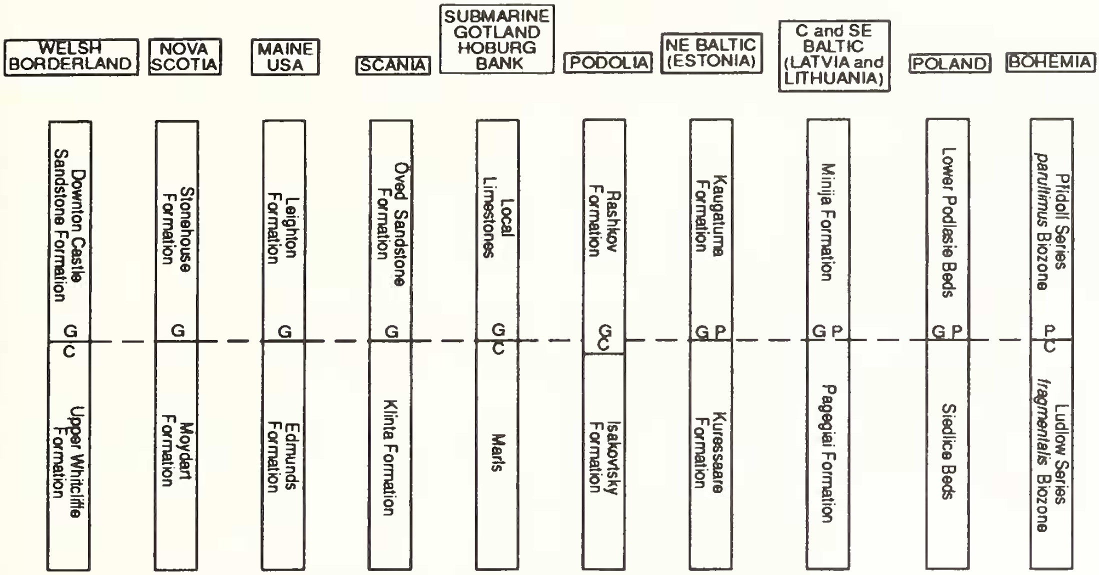
International correlation

The base of the Přídolí Series is defined at Požáry near Prague (Bassett 1985), within bed 96 at a level coincident with the first occurrence of *Monograptus parultimus* (the base of the *parultimus* Biozone). The stratotype section has been sampled in detail for graptolites, chitinozoans, conodonts, trilobites, bivalves and brachiopods (Jaeger *et al.* 1981; Paris 1981; Kříž *et al.* 1983, 1986; Paris and Kříž 1984; Kříž 1989, 1992). Graptolites are the most important biozonal fossil group for the type Přídolí and allow detailed correlation of the Přídolí Series throughout the Prague Basin.

Conodonts. The stratigraphically important conodont taxa *O. r. eosteinhornensis* and *O. crispa* have been recovered from the section at Požáry. *O. r. eosteinhornensis* ranges from *c*. 2 m below the base of the Přídolí Series at Požáry, to a level above the top of the Přídolí Series (Chlupáč *et al.* 1980; Kříž *et al.* 1983). *O. crispa* is stratigraphically restricted to the uppermost Ludlow Series at Požáry, appearing only in beds 87–91, and last occurs at a level 0·5 m below the base of the Přídolí Series (Kříž 1989, text-fig. 67). There is a similar situation throughout the Barrandian Basin: *O. crispa* last occurs just below the base of the *parultimus* Biozone at Lochov Marble Quarry, Lochov Cephalopod Quarry, Hvížďalka, Koledník Quarry and at Kosov (Kříž *et al.* 1986; Kříž 1992).

Conodonts from the Upper Whitcliffe Formation at Ludlow offer a direction correlation between the Welsh and Prague basins. Rare specimens of *O. r. eosteinhornensis* occur in collections from the uppermost Ludlow Series at Ludlow and at other localities across the Welsh Borderland (Collinson and Druce 1966; Aldridge 1975, 1985; Aldridge *et al.* 1980; Aldridge and Schönlaub 1989; present study); the subspecies has also been recovered from the Ludlow Bone Bed Member at Ludlow (Walliser 1966). The stratigraphical ranges of *O.* cf. *crispa* and *O. r. eosteinhornensis* overlap at the top of the Ludlow Series at Ludlow (Text-fig. 7). However, *O. crispa* has a much shorter stratigraphical range in both the Welsh and Prague basins, and therefore has greater correlative potential. Until the present study, only one reported occurrence of *O.* cf. *crispa* (Pl. 3, fig. 3) had been documented from Britain, 0·3 m below the Ludlow Bone Bed at Ludford Lane, Ludlow (Aldridge and Smith 1985; Aldridge and Schönlaub 1989). This occurrence marked the first (and last) occurrence of *O. crispa* in the Welsh Basin and therefore could be correlated only with the first occurrence of *O. crispa* at Požáry, at a level 2·75 m below the top of the Ludlow Series. Consequently it has been suggested (Schönlaub 1986; Aldridge and Schönlaub 1989), that the base of the Přídolí Series at Ludlow occurs at a level above the Ludlow Bone Bed. Two specimens of *O. crispa* have been recovered from the Upper Whitcliffe Formation as part of the present study, one at Tite's Point, Severn Estuary (Pl. 3, fig. 1) and another at Prior's Frome in the Woolhope inlier (Pl. 3, fig. 2). A broken specimen of *O.* cf. *crispa* (Pl. 3, fig. 9) has been recovered from sample 18/1 at Ludford Corner (loc. 18), and a specimen of *O.* cf. *crispa* recovered from the topmost bed of the Upper Whitcliffe Formation at Aston Munslow, Shropshire (Pl. 3, fig. 8). This latter specimen has similar dentition, cavity shape and outline to unequivocal specimens of *O. crispa*, although the curved posterior termination to the element is not well developed (Pl. 3, fig. 8). These new occurrences confirm the presence of *O. crispa* in the Welsh Basin towards the end of deposition of the Upper Whitcliffe Formation, and more importantly provide a range for *O.* cf. *crispa* at Ludford Corner and Ludford Lane. *O.* cf. *crispa* can now be shown to range from 0·15–0·3 m below the base of the Downton Castle Sandstone Formation at Ludlow (Text-fig. 7). This new conodont evidence from Ludlow and other localities in the Welsh Borderland, confirms that base of the Přídolí Series in Britain is very close to the level of the base of the Downton Castle Sandstone Formation. Taken in isolation, the occurrence of *O.* cf. *crispa* in the topmost bed of the Upper Whitcliffe Formation at Aston Munslow indicates that the base of the Přídolí Series is at least as high as the base of the Downton Castle Sandstone Formation and possibly at a level above its base. In the latter case, without the key graptolite *M. parultimus* it would not be possible to pinpoint the level of the base of the Přídolí Series in Britain.

O. crispa follows *O. snajdri* stratigraphically and is thought to be a direct phylogenetic descendant (Aldridge and Schönlaub 1989). *O. snajdri* is considered to be restricted to the Ludlow Series (Aldridge and Schönlaub 1989, text-fig. 172), even though *Spathognathodus* aff. *snajdri* has been recovered from the Äigu Member of the Kaugatuma Formation of Estonia (Viira 1982). The base of the Kaugatuma Formation is considered coincident with the base of the Přídolí Series, as *M. ultimus* occurs at the base of the formation in the south-east Baltic (Kaljo 1990). Viira (1982) was not able to distinguish *S. snajdri* from *S. crispa*. However, *O. crispa* is now regarded as confined to



TEXT-FIG. 14. Correlation of the base of the Downton Castle Sandstone Formation through Europe and eastern North America using ostracode, graptolite and conodont faunas. The correlations of the local lithostratigraphical units are based on Bassett *et al.* (1982; 1989) and Siveter (1989). G, refers to the occurrence of the key ostracode *F. groenvalliana* within a formation; P, denotes the presence of the graptolite *M. parultimus*; C, indicates the presence of the conodont *O. crispa*. The symbols are not intended to indicate exact stratigraphical positions and the columns are not drawn to scale.

the Ludlow Series of the Baltic (Männik and Viira 1990); thus the material that Viira (1982) identified as *Spathognathodus* aff. *snajdri* probably includes specimens of *O. snajdri* from the Přídolí Series.

If *O. snajdri* is considered to be a predecessor to *O. crispa*, the occurrence of *O.* cf. *snajdri* above the base of the Rushall Beds at Prior's Frome suggests that there the base of the Přídolí Series should be at least as high as the last occurrence of *O. snajdri*. Conodont faunas from the Barrandian Basin (Schönlaub 1986) indicate that *O. snajdri* and *O. crispa* occur together. *Ozarkodina snajdri* also occurs higher than *O. crispa* in the Whitcliffe Formation at Tite's Point and the Upper Perton Beds at Prior's Frome. In the Welsh Basin the first appearance of *O. crispa* stratigraphically follows that of *O. snajdri*, though their stratigraphical ranges overlap, and *O. snajdri* continues into the Přídolí Series. It must also be noted that the specimens of *O.* cf. *snajdri* in the Rushall Beds at Prior's Frome are abraded and the possibility that the specimens have been reworked cannot be discounted. The occurrence of *O.* cf. *snajdri* above the base of the Rushall Beds cannot, therefore, be taken as an indication that the base of the Přídolí Series should be placed above the base of the Rushall Beds at Prior's Frome.

Ostracodes. The ostracodes in the type section for the base of the Přídolí Series in the Barrandian area are provincial and in need of further study (Kříž 1989; Siveter 1989; Hansch 1993); therefore, direct correlation with British ostracode faunas cannot be made. Using the ostracode *F. groenvalliana* and graptolites, the base of the Downton Castle Sandstone Formation can be correlated to Maine, Nova Scotia, Podolia, Scania, Gotland, the Baltic, Poland and Bohemia (Martinsson 1967; Siveter 1978, 1989, text-fig. 164, and references therein; Bassett *et al.* 1982). Text-figure 14 summarizes the chain of correlation based on Bassett *et al.* (1982, text-fig. 7; 1989) and Siveter (1989, text-fig. 164), including conodont data and recent information from Podolia.

The correlative link between ostracode and graptolite faunas occurs in the Kaliningrad region of the Baltic which then provides a link with the graptolite biozonal schemes of Polish and hence, Bohemian successions. *F. groenvalliana* and the key graptolite *M. parultimus* occur together only in the Kaliningrad region, but at separate stratigraphical levels in the Dubovskoe borehole; the first occurrence of the former occurs 68 m higher than the first occurrence of the latter (Kaljo and Sarv 1976, text-fig. 1; Hansch *et al.* 1991). The first occurrence of *F. groenvalliana* has been recognized within the fully marine Äigu Member of the Kaugatuma Formation of Estonia (Kaljo and Sarv 1966; Sarv 1968, 1971). At Ohesaare on Saaremaa, where the base of the Kaugatuma Formation is shown as coincident with the base of the *parultimus* Biozone, *F. groenvalliana* has also been reported 8 m above the base of the formation (Bassett *et al.* 1989, text-fig. 123). In Lithuania the first occurrence of *F. groenvalliana* coincides with the lowest sample taken within the Kaugatuma Regional Stage (4 m above its base) in the Stoniskiai borehole (Sarv 1977, text-fig. 7). In the Pajevonis 13 borehole of Lithuania, *M. parultimus* is reported at the base of the Minija Formation (Paškevičius 1979). Accepting the correlation of the base of the Minija Formation with the base of the Kaugatuma Stage (Bassett *et al.* 1989, text-fig. 118), this indicates that *F. groenvalliana* and *M. parultimus* first appear at approximately the same level in Lithuania.

Martinsson (1964) reported *Frostiella lebiensis* at a restricted range of 681·75–694·40 m in the Łeba 1 borehole in northern Poland. *F. lebiensis* is now recognized as a synonym of *F. groenvalliana* (Hansch *et al.* 1991); the species occurs within the Lower Podlasie Beds of Poland (Text-fig. 14). Tomczyk (1968) recorded graptolites from Polish boreholes including the Lebork Borehole where *M. ultimus* directly follows *M. formosus*. Recovery from most of the Polish boreholes is incomplete, except for the Lebork borehole where it is almost complete. Tomczyk (1968) used the upper limit of *M. formosus* to define the boundary between the Ludlow and the Podlasie Beds. The correlation chart for the Polish Silurian (Tomczykowa and Witwicka 1974, text-fig. 2) based on ostracode, graptolite, and trilobite evidence, places the last occurrence of *M. formosus* in the Łeba 1 borehole at a level between 800 and 850 m, at least 230 m below the occurrences of *F. groenvalliana* (*lebiensis*) reported by Martinsson (1964). The first occurrence of *F. groenvalliana* is therefore consistently above the level of the base of the *parultimus* Biozone, most notably at Kaliningrad which is the only locality where the two species occur in the same section.

Since Bassett *et al.* (1982) outlined the correlation of the base of the Downton Castle Sandstone Formation across Europe, further information has become available on the distribution of the ostracode *F. groenvalliana* and the resolution of graptolite biozonal schemes has been increased. A number of potential problems regarding the correlation noted by Bassett *et al.* (1982) can now be addressed.

1. 'There is currently some discrepancy in the interpretation of the ranges of graptolites associated with the lowest Downton ostracode assemblages in Poland' (Bassett *et al.* 1982, p. 18). Ostracode assemblages from the Lower Podlasie Beds in Poland correlate within the *ultimus* Biozone but occur above horizons containing *M. formosus* (Tomczyk 1968, 1970; Tomczykowa and Witwicka 1974). Levels with *M. formosus* were formerly regarded as being within the *ultimus* Biozone, although the taxonomy of the *formosus* group was poorly known (Teller 1969; Jaeger 1977). The graptolite biozonation for the Přídolí in the Prague Basin (Jaeger 1986) shows that the range of *M. formosus* spans the Upper Ludlow *fragmentalis* Biozone and the Přídolí *parultimus* and *ultimus* biozones. The *ultimus* Biozone has now been subdivided into a (lower) *parultimus* Biozone and (upper) *ultimus* Biozone, as *M. parultimus* and *M. ultimus* are almost certainly successive members of a lineage (Jaeger 1986). Occurrence of the ostracode *F. groenvalliana* above levels containing *M. formosus* is not therefore inconsistent with the occurrence of *F. groenvalliana* above the base of the *parultimus* Biozone.

2. Various reviews of the correlation of the Silurian of the East Baltic (Kaljo and Sarv 1966; Kaljo 1970, 1978) have expressed differing opinions as to the correlation of the base of the Downton Group with the Kaugatuma and underlying Kuressaare beds (Bassett *et al.* 1982, p. 18). Kaljo (1979) correlated the base of the Kuressaare Beds with the base of a broad *formosus-ultimus* graptolite interval, with *F. groenvalliana* entering slightly higher in the succession (at the base of the Kaugatuma Beds), suggesting that the base of the Kaugatuma Beds is approximately coincident with the base of the *ultimus* graptolite Biozone (Bassett *et al.* 1982). The latest correlative schemes

for the Silurian of the Baltic place the Kuressaare Formation at the top of the uppermost Ludlow *formosus* Biozone and the base of the Kaugatuma Formation coincident with the base of the *parultimus* Biozone (Bassett *et al.* 1989, text-fig. 118; Kaljo 1990, text-fig. 2).

3. The position of the base of the Minija Formation in the East Baltic is marked as uncertain (Bassett *et al.* 1982, text-fig. 7) and possibly at a level below the base of the *ultimus* Biozone. Bassett *et al.* (1982, p. 17) reported that the basal 'Downton' ostracode fauna in Latvia and Lithuania entered at or closely above the base of the Minija Formation, but it is unclear from what authority this has been cited. Paškevičius (1982) and Sidaraviciene (1986) confirmed that *F. groenvalliana* is present at the base of the Minija Formation in the Stoniskiai, Vidukle and no. 110 (Arjogal profile) boreholes of Lithuania. If the base of the Minija Formation is below the base of the *parultimus* Biozone (see Bassett *et al.* 1982, text-fig. 7) then the correlation using *F. groenvalliana* is wrong. The latest published correlation chart for the Silurian of the Baltic (Bassett *et al.* 1989, text-fig. 118) places the base of the Minija Formation coincident with the base of the *parultimus* Biozone, but a dotted line is used as there is still a degree of uncertainty concerning the exact position of the base of the formation.

Dr David J. Siveter (pers. comm.) has examined material from Podolia and considers *F. modesta* Abushik, 1971, conspecific with *F. groenvalliana*. This further extends the geographical distribution of the species to Podolia where it occurs 17 m above the base of the Rashkov Formation (Abushik *et al.* 1985; Koren' *et al.* 1989). *Ozarkodina crispa* last occurs 5 m above the base of the Rashkov Formation in Podolia (Abushik *et al.* 1985; Koren' *et al.* 1989, text-fig. 105). Conodont evidence therefore suggests that the base of the Přídolí Series is at a level at least 5 m above the base of the Rashkov Formation. This provides an additional example of *F. groenvalliana* closely stratigraphically following *O. crispa*, but with no overlap in their ranges (cf. Ludford Corner, Ludlow). According to Viira (1982) and Schönlaub (1986) it is possible that *O. crispa* ranges into the lowermost Kaugatuma Formation of the east Baltic and, therefore, occurs above levels containing *F. groenvalliana*. As discussed above, *O. crispa* is now considered to be confined to the Upper Paadle Formation, at a level below the Kaugatuma Formation (Männik and Viira 1990).

Frostiella groenvalliana is not always present at the base of the lithostratigraphical units shown in Text-figure 14. However, the distribution is remarkably consistent across the whole of Europe, with *F. groenvalliana* always occurring above the base of the *parultimus* Biozone and occurrences of *O. crispa* and never below these levels. The evidence currently available therefore suggests that *F. groenvalliana* is restricted to the Přídolí Series. The correlation of the base of the Downton Castle Sandstone Formation in the Welsh Borderland with the base of the Přídolí Series in the Czech Republic using the ostracode *F. groenvalliana* is regarded as approximate in terms of the detailed stratigraphical resolution of the present study. The correlation is indirect as the two key species are both present only at Kaliningrad, and then at different stratigraphical levels (see above; Kaljo and Sarv 1976). Lithostratigraphical correlation between local units has to be used to provide the link between ostracode and graptolite faunas. Often there is a degree of uncertainty regarding these correlations, for example with the position of the base of the Minija Formation in western Latvia and western Lithuania. Sampling in Baltic, Scanian, Polish and North American sections has not been carried out to the same high resolution as at the stratotype for the base of the Přídolí Series at Požáry, or at Ludlow in the present study. More detailed sampling is therefore needed on and around the stratigraphical level at the base of the *parultimus* Biozone to recover more detailed records of *F. groenvalliana* and to enable occurrences to be more accurately tied in with the base of the *parultimus* Biozone. With only a limited sample size, borehole data does not often permit detailed studies of these faunas. Borehole recovery is seldom complete, and important faunas may have been lost.

Indirect and approximate correlation using ostracodes and graptolites (Text-fig. 14) suggests that the base of the Přídolí Series in Britain is coincident with the base of the Downton Castle Sandstone Formation. Conodont faunas from the uppermost Upper Whitcliffe Formation at Ludlow and across the Welsh Borderland offer a direct correlation with the Barrandian Basin and suggest that the base of the Přídolí Series in Britain is at least as high as the base of the Downton Castle

Sandstone Formation and possibly a little higher than this. At present, the exact position of the base of the Přídolí Series in Britain cannot be demonstrated because of the absence of the key graptolite species *M. parultimus*; the current state of knowledge on British, European and North American conodont, ostracode and graptolite correlations suggests that the base is coincident with the base of the Downton Castle Sandstone Formation at Ludlow.

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